QC
1
.P5812

VOLUME XIII NUMBER 2

THE PHYSICAL REVIEW

A JOURNAL OF EXPERIMENTAL AND THEORETICAL PHYSICS

CONDUCTED BY

EDWARD L. NICHOLS

ERNEST MERRITT, and FREDERICK BEDELL

LXVI

AUGUST 1901

TABLE OF CONTENTS

Frontispiece

The Visible Radiation from Carbon I — EDWARD L. NICHOLS — 65

Magnetization of Iron, Steel and Nickel Wires by Intermittent Current — K. HONDA and S. SHIMIZU — 81

The Specific Heat of Solutions which are not Electrolytes II — WILLIAM FRANCIS MAGIE — 91

Polarization and Internal Resistance of Electrolytic Cells I — MARTIN D. ATKINS — 102

Note: Franz Emil Melde — KARL SCHAUM — 125

New Books: *Crew:* The Elements of Physics; *Snyder and Palmer:* One Thousand Problems in Physics; *Caldwell and Fish:* Notes and Questions for the Dynamo Laboratory — 127

COPYRIGHT, 1901, BY THE MACMILLAN COMPANY

PUBLISHED FOR CORNELL UNIVERSITY

BY THE MACMILLAN COMPANY

LANCASTER, PA., AND NEW YORK

LONDON: MACMILLAN AND CO., LTD

BERLIN: MAYER AND MUELLER

THE PHYSICAL REVIEW

A JOURNAL OF EXPERIMENTAL AND THEORETICAL PHYSICS

CONDUCTED BY

EDWARD L. NICHOLS
ERNEST MERRITT, AND FREDERICK BEDELL

Two volumes of THE PHYSICAL REVIEW are published annually, these volumes beginning in July and January, respectively, and containing at least five numbers each. The price of subscription is two dollars and fifty cents a volume (five dollars a year), or fifty cents a number. Subscriptions should be sent to the publishers. THE MACMILLAN COMPANY, 41 *North Queen Street, Lancaster, Pa.*, or 66 *Fifth Avenue, New York;* Messrs. MACMILLAN & CO., LTD., *London;* or to Messrs. MAYER AND MUELLER, *Berlin.*

Previous to Volume V. (July–December, 1897) THE PHYSICAL REVIEW was published in annual volumes, each containing six bimonthly numbers, beginning with the July–August number, 1893. These may be obtained from the publishers at the former subscription price, three dollars per volume.

Subscribers who desire to have their copies of the REVIEW sent to them with the edges cut, can so obtain them by informing the publishers to that effect.

Correspondence relating to contributions should be addressed to the editors, at *Ithaca, New York.*

Manuscript intended for publication in THE PHYSICAL REVIEW must be communicated by the author; when publication in other journals is contemplated, notice to that effect should be given.

The authors of original articles published in the REVIEW will receive one hundred separate copies in covers, for which no charge will be made; additional copies, when ordered in advance may be obtained at cost.

PUBLISHED FOR CORNELL UNIVERSITY

THE MACMILLAN COMPANY

RICHARD MÜLLER-URI Braunschweig (Germany)

Manufacturer of

Blown Glass for Scientific Purposes

Reduction Apparatus

All Kinds of Lecture Apparatus and Supplies for Chemical and Physical Laboratories

Chas. R. Cross' Vacua Scale—Röntgen Tubes—McFarlan Moore Apparatus—Elster & Geitel's Transformer without Oil Insulation and Tesla Series—Spectrum Tubes (Argon, Helium) with pure Gases or Solids—Electrical Tubes after Arons, Braun, Crookes, Ebert, Geissler, Goldstein, Hittorf, Lecher, Lenard, Puluj, Zehender—Radiometers—Photo-Electric Cells and Apparatus (Selenium, etc.), Electrometer Exner.—Atmospheric Electricity Apparatus.

Sterilizer for General Work

Sole Maker and Furnisher of Patented Constructions:

115874 Röntgen-Tube for low tension currents
112835 Current Demonstrating Apparatus
58795 Perforator (Extractor)
38217 Sterilizor

Dry Pile

Apparatus for Gas-Analysis and Titration

Best Chemical Glassware

Professor Weber's Glass and Jena Normal Glass

Catalogues and Special Prospectus on Desire

WM. GAERTNER & CO.

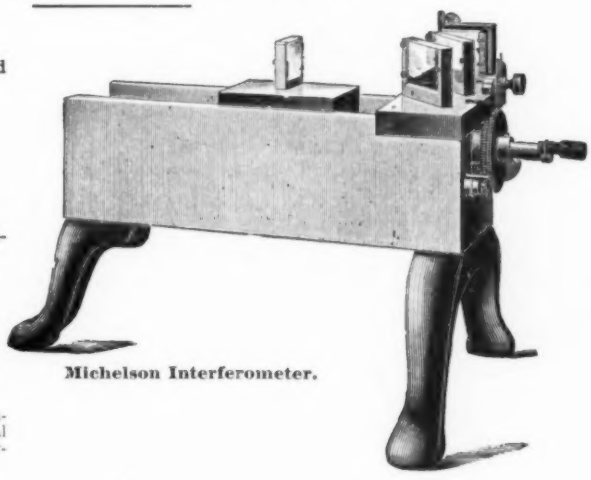
Astronomical and Physical Apparatus

5347 and 5349 Lake Avenue, CHICAGO

SPECIALTIES

Standard Apparatus of new and improved designs
Astronomical Telescopes
Spectroscopes
Micrometers
Michelson Interferometers and Echelon Spectroscopes
Reading-microscopes and Telescopes
Bolometers
Heliostats
Dividing Engines, Comparators
General Laboratory Apparatus
Universal Laboratory-supports

Special attention paid to the construction of instruments for original investigation after our own or furnished designs.



Michelson Interferometer.

SCIENCE

A WEEKLY JOURNAL DEVOTED TO THE ADVANCEMENT OF SCIENCE

EDITORIAL COMMITTEE

S. NEWCOMB, Mathematics; R. S. WOODWARD, Mechanics; E. C. PICKERING, Astronomy; T. C. MENDENHALL, Physics; R. H. THURSTON, Engineering; IRA REMSEN, Chemistry; J. LE CONTE, Geology; W. M. DAVIS, Physiography; HENRY F. OSBORN, Paleontology; W. K. BROOKS, C. HART MERRIAM, Zoology; S. H. SCUDDER, Entomology; C. E. BESSEY, N. L. BRITTON, Botany; C. S. MINOT, Embryology, Histology; H. P. BOWDITCH, Physiology; J. S. BILLINGS, Hygiene; J. MCKEEN CATTELL, Psychology; J. W. POWELL, Anthropology.

The past history of SCIENCE is a sufficient guarantee of its future usefulness. Such a JOURNAL is essential to the advance and proper recognition of the scientific work of each country, and in America where men of science are scattered over a great area, with no single center for personal intercourse, it is peculiarly needful. With the growth of science and scientific institutions in America SCIENCE will occupy an even more important position than at present. It will continue to set a standard to the popular press in its treatment of scientific topics, to secure that general interest in science so essential to its material support, to enlarge the place of science in education and in life, and to demonstrate and increase the unity of science and the common interests of men of science.

SCIENCE is published every Friday. Each number contains forty double-column pages of reading matter, and over 2000 such pages, making two large volumes, are published annually. The subscription price is only $5.00 per year or $2.50 per volume. Single numbers are sold for 15 cents.

PUBLISHED BY

THE MACMILLAN COMPANY

66 FIFTH AVENUE, NEW YORK

WESTON

STANDARD
PORTABLE
DIRECT-READING

VOLTMETERS
MILLIVOLTMETERS
VOLTAMMETERS
AMMETERS
MILLAMMETERS
GROUND DETECTORS AND CIRCUIT TESTERS
WATTMETERS
OHMMETERS
PORTABLE GALVANOMETERS

WESTON STANDARD PORTABLE DIRECT-READING VOLTMETER FOR DIRECT CURRENT

Our Portable Instruments are recognized as The Standard the world over. The Semi-Portable Laboratory Standards are still better. Our Station Voltmeters and Ammeters are unsurpassed in point of extreme accuracy and lowest consumption of energy

---

Weston Electrical Instrument Co.

114-120 William St., NEWARK, N. J., U. S. A.

STANDARD BOOKS ON
ELECTRICITY AND MAGNETISM

The Theory of Electricity and Magnetism

By A. G. WEBSTER, A.B. (Harv.), Ph.D. (Berol.)

Assistant Professor of Physics, Director of the Physical Laboratory, Clark University, Worcester, Massachusetts

8vo. Cloth. pp. xii + 576. Price, $3.50, net

Elementary Lessons in Electricity and Magnetism

By SILVANUS P. THOMPSON, D.Sc., B.A., F.R.A.S.

New Edition With Illustrations. 16mo. Cloth. $1.40, net.

"I consider Thompson the best book of its size and nature on the subject of electricity, and have had frequent occasion to recommend it to friends and students. It is the only book that is not simply a rearrangement or reproduction of the old treatise."

—WILLIAM A. HALLOCK, Ph.D., *Columbia University, New York City.*

The Principles of the Transformer

By FREDERICK BEDELL, Ph.D.

Assistant Professor of Physics in Cornell University

8vo. Cloth. 250 Illustrations. Price, $3.25, net

This work constitutes a systematic treatise on the Alternating Current Transformer, and a ogical exposition of the principles involved, of the most modern methods of transformer design, construction, and testing, and of transformer systems of distribution.

A Text-Book on Electro-Magnetism

AND THE CONSTRUCTION OF DYNAMOS

By DUGALD C. JACKSON, B.S., C.E.

Professor of Electrical Engineering, University of Wisconsin

12mo. Cloth. Price, $2.25, net

Alternating Currents and Alternating Current Machinery

By DUGALD C. JACKSON, C.E. *University of Wisconsin* **and JOHN P. JACKSON, M.E.** *Pennsylvania State College*

12mo. Cloth. pp. xvii + 729. Price, $3.50, net

"I like the way in which they develop their theory and make practical applications. I feel sure that the book will receive a hearty welcome."

—GEO. W. PATTERSON, Jr., *Asst. Professor of Physics, University of Michigan.*

The Storage Battery

A PRACTICAL TREATISE ON THE CONSTRUCTION, THEORY AND USE OF SECONDARY BATTERIES

By AUGUSTUS TREADWELL, Jr.

Cloth. 12mo. pp. xx + 257. Price, $1.75, net

Electricity in Town and Country Houses

By PERCY E. SCRUTTON.

Second Edition. Fully Illustrated. 12mo. Cloth. pp. xii + 148. Price, $1.00

A brief and simple statement of the first principles of the application of electricity to the needs of the home, for heating, cooking, lighting, etc. A popular and untechnical book, freely illustrated.

THE MACMILLAN COMPANY

New York: 66 Fifth Avenue

BOSTON CHICAGO SAN FRANCISCO

The

General Electric Company's

Pocket Ammeters

INCLINED COIL POCKET AMMETER (Covered)

of twenty-five amperes' capacity can be used upon either direct or alternating current, and gives accurate readings for experimental work in the laboratory.

INCLINED COIL POCKET AMMETER (Uncovered)

This pocket ammeter is one of a complete set of portable inclined coil electrical measuring instruments, for use in the laboratory, central station and outside work.

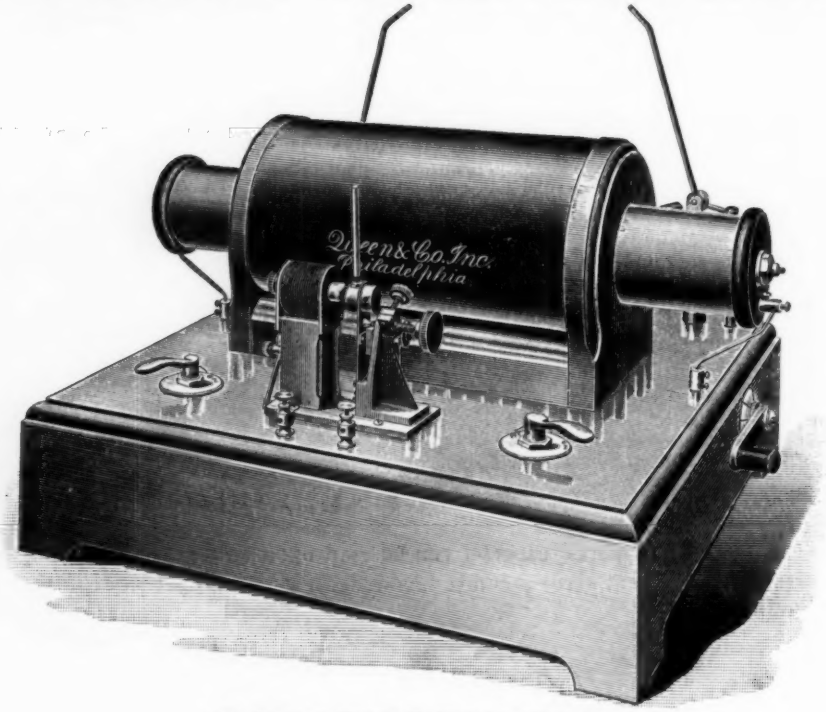
GENERAL ELECTRIC COMPANY

Main Office: SCHENECTADY, N. Y.

Sales Offices in All Large Cities

For CANADA: Address the CANADIAN GENERAL ELECTRIC COMPANY, Toronto, Can.

Queen Instruments



12″ SPARK TYPE Z INDUCTION COIL

A NEW INDUCTION COIL. This Instrument is the result of much experimental work and by a new arrangement of **Primary, Secondary** and **Condenser,** we have obtained a much **thicker** and **heavier secondary spark** than heretofore. The **Condenser** is of **double** the **capacity** ordinarily used. The **Vibrator** is our latest improved **mutiple type** operating regardless of the current strength in primary. The **Switches** cannot arc and burn, and indicate directly whether current is **"on"** or **"off."** The **Woodwork** is of the **finest quality** of **mahogany** with **high finish.** *Our X-Ray Catalogue describes many other forms of Coils.*

ELECTRICAL, BIOLOGICAL, CHEMICAL AND SCIENTIFIC APPARATUS

Queen & Co., Inc.

J. G. GRAY, President

1010 CHESTNUT STREET,
PHILADELPHIA, PA.

New York Branch,
59 Fifth Ave.

FRANZ EMIL MELDE

Volume XIII. *August, 1901.* *Number 2.*

THE

PHYSICAL REVIEW.

THE VISIBLE RADIATION FROM CARBON.[1] I.

By Edward L. Nichols.

THE law of radiation has for a long time been considered by physicists as a subject of high interest, and numerous investigations looking to the establishment of a general relation between radiation and temperature have been made both from the theoretical and the experimental standpoint. The earliest attempts to determine incandescence in its relation to temperature were made with platinum. Draper[2] in 1847 made observations upon a wire of that metal heated by an electric current. The temperatures were from the expansion of the wire. Zöllner[3] in 1859 compared the light emitted by incandescent platinum with the heat evolved.

E. Becquerel,[4] who made an extensive study of visible radiation from various solids at high temperatures, used thermo-elements of platinum and palladium, calibrated by reference to melting points and with the air thermometer. A partial separation of the rays was effected by means of colored screens. He found that opaque bodies, such as lime, magnesia, platinum and carbon at the same temperature had very nearly equal emissive powers, a conclusion vigorously contested by his contemporaries, but explained in the light of later work, by the fact that the glowing bodies were en-

[1] An investigation carried on in part by means of an appropriation from the Rumford Fund for Research. Read at the meeting of the American Association for the Advancement of Science in New York, June 27, 1900.

[2] Draper, Philosophical Magazine, Vol. XXX., p. 345 (1847).

[3] Zöllner, Photometrische Untersuchungen (1859).

[4] Becquerel, Annales de Chimie et de Physique (3), 68, p. 47 (1863).

closed in a long earthen tube. The conditions for ideal blackness were thus approximately fulfilled. He likewise made photometric observations upon wires electrically heated and found the light to increase much more rapidly than the emitted heat.

Although some of Becquerel's results were at fault, particularly his estimation of temperature above the melting point of gold, his work is especially noteworthy in that he employed many of the methods to which, in the hands of later investigators, our knowledge of the laws of incandescence is due. He established the fact of the direct proportionality of the logarithm of the intensity of radiation to the temperature and pointed out the possibility of optical pyrometry.

In 1878 Crova[1] used the Glan spectrophotometer in the comparison of various sources of light such as candles, gas flames, the lime light, the arc light and sunlight, and proposed an optical method for the measurement of temperatures.

In 1879[2] I published the results of a series of measurements made in this manner upon the visible radiation from platinum at various temperatures. At that time, the measurement of high temperatures by means of thermo-elements, of platinum and platinum-rhodium, or platinum-iridium, had not been developed and the determination of the temperature from the change of resistance of the metal was, as has been previously pointed out by Siemens, a matter of great uncertainty on account of the varying performance of different samples of platinum. This difficulty, which was due to the impurities contained in the metal, has since been largely overcome and platinum thermometry has, through the study of Callendar and others, been advanced to the position of an operation of precision; but at that time I was forced to content myself in the investigation just referred to with an expression of temperature of the glowing platinum in terms of its increase of length.

Work upon the incandescence of carbon was first taken up in a serious manner after the development of the incandescent lamp.

Schneebeli,[3] in 1884, made some observations upon the total

[1] Crova, Comptes Rendus, 57, p. 497 (1878).

[2] Nichols: Ueber das von glühendem Platin ausgestrahlte Licht. Göttingen, 1879; also American Journal of Science, Vol. 18, p. 446 (1879).

[3] Schneebeli, Wiedemann's Annalen, 22, p. 430 (1884).

radiation and candle power of the Swan lamp. He made no estimation of temperatures.

In the same year Schumann[1] published his very complete spectrophotometric comparison of the various incandescent lamps in use in Germany. Lucas,[2] in 1885, heated arc-light carbons in vacuo, estimated their temperature from the current employed and measured the light given in carcels. I shall refer to his work in some detail later.

In 1887 H. F. Weber[3] began his studies of the spectrum of the incandescent lamp. He found that the first light to appear was not that of the region nearest the red end of the spectrum but corresponded in wave-length to the region of maximum luminosity and that at their low temperatures the spectrum was devoid of color. Stenger[4] in the same year corroborated Weber's observations and offered what has since been received as the proper explanation of the phenomenon.

In 1889 I published in colaboration with W. S. Franklin[5] a series of spectrometric comparisons of incandescent lamps maintained at various degrees of brightness. No attempt was made to determine temperatures. In 1891, H. F. Weber[6] read a paper at the Electrotechnical Congress in Frankfort on the general theory of the glow lamp. By means of numerous measurements through a wide range of incandescence, made upon lamps with treated and untreated filaments, constants were established for his empirical formula for the relation of radiation and temperature.

The infra-red spectrum of carbon has, since the appearance of the incandescent lamp, likewise been subjected to measurement. Abney and Festing[7] in 1883 published curves for the distribution of energy in the spectrum of such lamps from measurements made with the thermopile. In 1894 I compared with the help of the same instru-

[1] Schumann, Elektrotechnische Zeitschrift, 5, p. 220 (1884).

[2] Lucas, Comptes Rendus, 100, p. 1454 (1885).

[3] Weber, Wiedemann's Annalen, 32, p. 256 (1887).

[4] Stenger, Wiedemann's Annalen, 32, p. 271 (1887).

[5] Nichols and Franklin, Am. Jour. of Science, 38, p. 100 (1889).

[6] Weber, Bericht des internationalen Electrotechnikercongresses zu Frankfurt am Main, p. 49 (1891); also PHYSICAL REVIEW, Vol. 2, p. 112.

[7] Abney & Festing, Philosophical Magazine (5), 16, p. 224 (1883); also Proceedings of the Royal Society, 37, p. 157 (1884).

ment and a highly sensitive galvanometer the infra-red spectra of lamps with black and gray filaments.[1]

Of late years attention has been devoted especially to the problem of the law of radiation from an ideal black body and various formulæ have been proposed by means of which the rise of radiation of any single wave-length upon the one hand and of the total radiation on the other may be expressed as a function of the temperature. Interesting as this phase of the problem is from the point of view of theoretical physics, it is perhaps even more important to know the relation between temperature and radiation for actual surfaces.

APPARATUS AND OUTLINE OF METHOD.

I propose in the present paper to describe an attempt to measure the temperature of carbon rods rendered incandescent by the passage of an electric current, and to make spectrophotometric comparisons of the visible radiation from their surfaces with the corresponding wave-lengths in the spectrum of an acetylene flame.

The carbons used for this purpose were produced by the well-known process of squirting a semi-fluid carbonaceous paste through a cylindrical opening. They were straight cylindrical rods 10 cm. in length and 2 mm. in diameter. Still larger rods would have been preferable but I was unable to obtain any of greater diameter than the above that were capable of withstanding the temperatures to which it was necessary to heat them. The rods were mounted horizontally in a massive metal box 40 cm. in length, 20 cm. wide, and 20 cm. in height. This box, which was made especially for this investigation, had openings at the ends through which, by means of air-tight plugs, the terminals of the rod could be introduced. Through one of these plugs, likewise, the platinum and platinum-rhodium wires of the thermo-element, by means of which the temperature measurements were made, entered the box. In one of the vertical sides of the box was a row of five circular plate glass windows, which could be removed for cleaning, through which the carbon could be seen and the spectrophotometric observations could be made. Other

[1] Nichols, PHYSICAL REVIEW, Vol. 2, p. 260 (1894).

openings in the top of the box and through the opposite sides served to connect it with a mercury air pump of the Geissler type and with manometers for the measurement of pressure. A vertical cross section of this part of the apparatus is shown in Fig. 1.

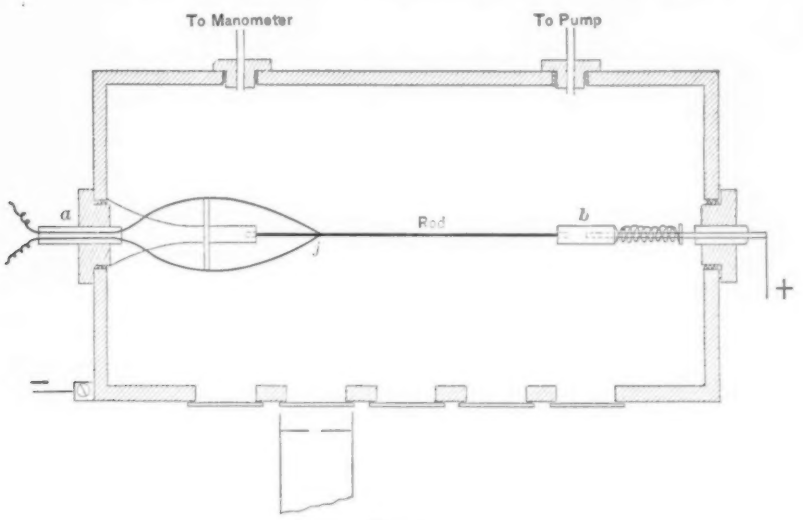


Fig. 1.

Attempts to locate by a variety of methods the hot junction of the thermo-element, by means of which the temperature of the surface of the rods was to be measured, in such manner that it would assume the temperature of that surface, made it only too clear that herein lay one of the chief difficulties of the investigation. It was found that any such junction, however small its size and however carefully it might be brought into contact with the surface of the rod, would not take even approximately the temperature of that surface; and recourse, after the failure of numerous other expedients, was had to the following plan, which although far from being free from objection, was found to be upon the whole the most reliable, and to give, when properly carried out, the most definite and satisfactory result.

By means of a drill made for the purpose from the smallest obtainable size of steel sewing needle, a minute hole was bored radially at the point upon the surface of the rod lying within the field of view of the spectrophotometer. This hole had an approximate

diameter of 0.03 cm. It extended to a depth equal to about one-half the radius of the rod and was conical in form. Platinum and platinum-rhodium wires to be used for the thermo-element were drawn to a diameter of 0.016 cm., and their free ends having been laid together side by side, were fused in the flame of the oxyhydrogen blowpipe so as to form a junction. This junction, which after the action of the blowpipe took the shape of a small bead of the combined metals, was trimmed down into conical form, until it would just enter the hole in the side of the rod, care being taken that the entire junction was beneath the surface. The wires leading from this junction were next sealed into a glass tube of about 2 mm. bore through the interior of which they were carried from end to end; care being taken that they should be nowhere in contact. They were held in place by fusing the glass around them at either end of the tube. This tube was inserted through an opening in the plug *a* (Fig. 1), carrying one terminal of the rod and there made air-tight by means of cement. One end of the carbon rod was then inserted in a clamp attached to the inner face of the plug and the wires at a distance of about 1 cm. from the junction were bent downward at right angles so as to bring the junction into position for insertion into the hole in the rod and to hold it there when inserted by the slight but sufficient spring action of the wires themselves. This arrangement of the junction and rod is indicated in Fig. 2.

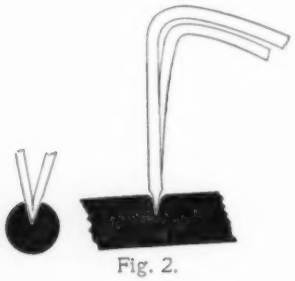


Fig. 2.

The introduction of the thermo-element having been successfully carried out by the method just described, it was possible to insert the plug, carrying the rod and thermo-junction with it, into the end of the box and to secure it in place; after which the free terminal of the rod was introduced between the jaws of a strong clip attached to the opposite plug (*b*, Fig. 1). This operation had to be performed through the open windows in the side of the box. These were then screwed tightly into place, and the box was ready for the exhaustion of the air.

This method of measuring the temperature of the surface, to be

successful, involved the fulfilling of several rather difficult conditions and the application of an important correction. To bore into the material of a carbon rod carrying a current in the manner described, necessarily disturbs more or less the flow of the current; and the changes of resistance thus introduced were likely to bring about decided changes of temperature in that neighborhood. In some instances, this became obvious when the rod was heated, the temperature being higher near the hole than elsewhere. Indeed, it was often possible to note with the eye the increased incandescence of the region in question. In all such cases the mounting was rejected. It was found possible, however, to so nearly compensate for this loss of carbon by the introduction of the platinum junction that no difference in the incandescence of the surface could be detected by the closest observation; and since differences of temperature which cannot be detected by the eye will be negligible in spectrophotometric work, this was taken as the criterion of a satisfactory mounting of the thermo-junction. Measurements were attempted only when this condition was fulfilled. It is likewise obvious that there is danger from the contact of the two wires of the thermo-junction with the sides of the hole in the rod. A branch circuit for the passage of the current is thus formed which includes the galvanometer coils, thus imperiling the integrity of the readings of electromotive force. This could be obviated only by having the wires touch the rod at points in an equipotential surface, and the fulfillment of this condition was determined by the reversal of the current through the rod and the absence of any effect of such reversal upon the galvanometer.

Another and more serious objection to the method, and one which could only be met by the introduction of a correction, lay in the fact that even with the smallest wires which could be used for a thermo-element a certain amount of heat would be carried away by conduction through the metal; so that the junction would never reach the full temperature of the surfaces with which it was in contact. I was at first inclined to think that this correction would be a small one, but attempts to measure the temperature of the acetylene flame by means of a similar thermo-element indicated that the loss of heat from this source was by no means to be neglected. The numerical value of this correction was accordingly determined

by direct experiment in the following manner. Thermo-elements drawn from the same pieces of wire but differing considerably in diameter were prepared. These were inserted two at a time in holes on opposite sides of a carbon rod and the rod was brought to incandescence by means of the current. The temperatures reached by these junctions were compared by means of the potentiometer and a curve was plotted showing the relation between the cross section of the wire in the thermo-element and the temperature of the junction. This curve, extended in the direction of decreasing cross section, served to indicate with at least a fair degree of accuracy the temperature which would have been reached by a thermo-element of *zero cross section* placed in contact with the surface to be measured. The difference between this temperature and that reached by a junction of any desired size gave the correction which was to be applied. The correction, as will be seen by inspection of the curve, Fig. 3, is a very large one, amounting even in the case

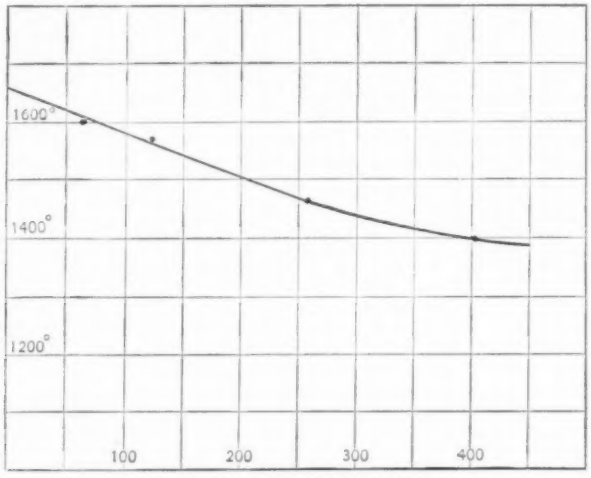


Fig. 3.

of the smallest wires which it was found practicable to use to about 85°. The results of the calibration agreed, however, so well with similar experiments made by placing thermo-junctions of various sizes in the non-luminous outer envelopes of the acetylene flame, of the ordinary gas flame, and of the flame of the candle,[1] that I feel warranted in placing much dependence upon them.

[1] Nichols, PHYSICAL REVIEW, X., p. 234.

This method of correcting for the loss of heat in a thermo-junction was first employed by Waggener[1] in his investigation of the temperature of the flame of the Bunsen burner. I became acquainted with his research, however, only after the completion of my experiments.

Calibration of the Thermo-Elements.

All our modern estimates of very high temperatures may be said to rest in one way or another upon extrapolation. The upper limit of usefulness of the air thermometer has been found to lie in the neighborhood of 1500°. It was at this temperature that Erhardt and Schertel[2] in their admirable but little-known research upon the melting points of alloys of silver, gold and platinum were obliged to abandon direct determination; and very closely, at which Holborn and Wien[3] and Holborn and Day[4] in their latest studies upon thermo-electric thermometry found that the indications of the air thermometer, even when constructed of the most refractory of modern porcelain began to become erratic. We have, it is true, the investigations of Violle[5] upon the melting points of the metals of the platinum group, but these, it must not be forgotten, are based upon an assumed value for the specific heat and this assumption is equivalent to the extrapolation of the curve of the variation of the specific heat with temperature. The observed values, by means of which this value was determined, all lie far below those of the melting points of the metals in question. It is necessary therefore in spite of the accumulation of indirect evidence of their approximate accuracy, to hold in reserve the assignment of absolute values of these melting points until by some means as yet unthought of, we shall be able to obtain direct experimental data. In the meantime they afford us the best present available basis for a temporary scale, our confidence in the approximate accuracy of which must rest upon the fact that the melting points for palladium, platinum, etc., as given by Violle are found to lie upon what may reasonably be

[1] Waggener, Wiedemann's Annalen, LVIII., p. 579 (1896).

[2] Erhardt and Schertel, Jahrbuch für das Hüttenwesen in Sachsen, 1879, p. 154.

[3] Holborn and Wien, Wiedemann's Annalen, XLVII., p. 107 (1892), and LVI., p. 360 (1895).

[4] Holborn and Day, American Journal of Science, VIII., p. 175 (1899).

[5] Violle, C. R., LXXXIX., p. 702 (1879).

supposed to be an extension of the curves experimentally determined for lower temperatures by means of the air thermometer. As for the various formulæ for the variation of electromotive forces of thermo-elements with the temperature, we must not lose sight of the fact that they are simply analytical expressions for experimentally determined relations and that the extensions of them to temperatures lying far beyond the experimental range is not to be regarded as more trustworthy than the extension of a curve by graphical methods. Under these circumstances I decided to content myself with the provisional acceptance of the following values for the melting points of gold, palladium and platinum, namely:

Gold,[1] 1064° C.
Palladium, 1500° C.
Platinum, 1775° C.

and to ascertain as accurately as possible the electro-motive force given by the thermo-elements used at these points. It was thought that by drawing a curve through them, and reading intermediate temperatures from this curve the values thus obtained would be as close as our present knowledge of the subject will admit. The platinum-platinum-rhodium wire used for my elements was obtained, as has already been stated, from Heræus in Hanau and was supposed to be of the same stock as that employed by Holborn and Wien. The fact that the electromotive force given by these thermo-elements when exposed to the temperature of melting platinum agreed very closely indeed with that obtained by extrapolation of their data, seems to indicate that the metals were identical with those used by them.

For the purpose of calibrating the thermo-elements, I employed a very simple method, the results of which, however, proved highly satisfactory. This method, which consists in exposing the hot junction to the layers of heated gas surrounding the acetylene flame and lying just outside the luminous envelop of that flame, has been described in some detail in a separate communication.[2]

[1] This value is that given by Holborn and Day in their second paper (American Journal of Science, X., p. 171 (1900).

[2] Nichols, On a New Method of Calibrating Thermoelectric Elements for Use in the Measurement of High Temperatures. [Livre Jubilaire dedié à H. A. Lorentz; La Haye, 1900, p. 339.]

The method is easily carried out and it is free from many of the most serious difficulties of the cumbersome operations usually employed, which involve the use of furnaces and of the porcelain bulb air thermometer. Fig. 4 contains the calibration curve of the thermo-

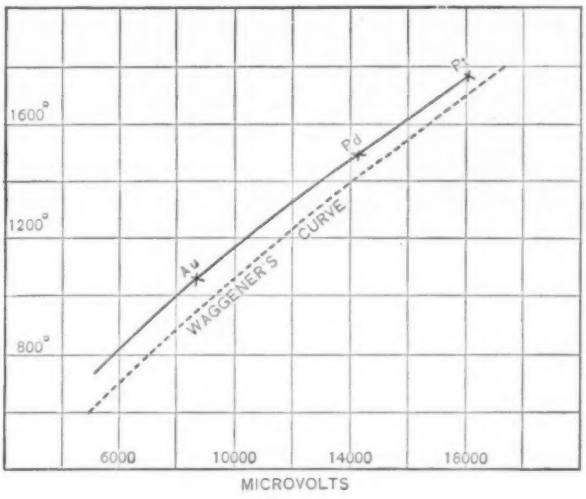


Fig. 4.

elements used in this investigation and likewise, for the purpose of comparison, a curve reproduced from Waggener's paper and extrapolated by him from the data given by Holborn and Wien. It will be seen that while the two curves are not identical, they are of the same general character and that the differences are not greater than experience would lead us to expect in the case of different thermo-elements, even where these are of platinum and of platinum-rhodium of the same manufacture. It is not a question of absolute electromotive forces but rather of the form of the curves; since what we really need is a criterion by means of which we can determine whether temperature readings based upon Violle's values for palladium and platinum are in reasonable agreement with those obtained by the extension of the curve of Holborn and Wien.

The Spectrophotometer.

The spectrophotometer used was a copy of the instrument designed by Lummer and Brodhun for the Imperial Institute in Char-

lottenburg. It consists of a one-prism spectroscope with two collimator tubes, placed at right angles to each other as shown in Fig. 5. Each of these tubes carries a slit the width of which is regulated by means of an accurate micrometer screw with a drum head divided into one hundred parts. By estimating tenths of a scale division, the width of the slits could be estimated to one one-thousandth of a revolution.

The essential feature of this photometer consists in the Lummer-Brodhun device (D), placed between the objective lenses of the two collimators and the prism, in such a position that the beam of light from one of the tubes is transmitted directly to the latter, while that from the other tube is bent through 90° by total reflection. The instrument was set up with collimator A in such a position that a portion of the surface of the incandescent rod lying nearest to the

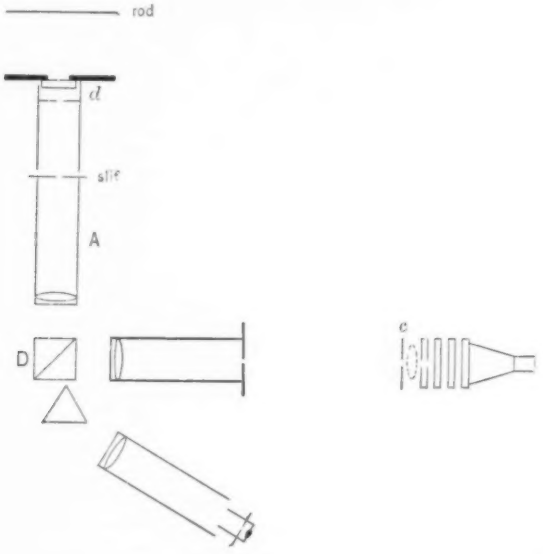


Fig. 5.

point at which the thermo-element had been inserted formed a field of illumination for the slit at a distance of about 25 cm. The region under observation was limited by means of a vertical diaphragm (d) 5 mm. in width which was mounted in a tube in front of a window of the metal vacuum box. The comparison source was the spectrum

of the brightest part of an acetylene flame set up in the axis of the other collimator at a corresponding distance and viewed through a circular aperture (c) 5 mm. in diameter, cut in a metal screen interposed between the flame and the slit and as near the former as practicable.

The acetylene flame was adopted as a comparison standard for the following reasons :

1. It possesses a continuous spectrum brighter in the less refrangible regions than that of any other controllable source of light.

2. The radiating material is finely divided carbon, presumably of a character not unlike that of the surface of the untreated rod.

3. The acetylene flame is the result of the combustion of a definite fuel (C_2H_2) burning under reasonably constant conditions. It is preferable in this regard to any of the ordinary gas or candle flames in which the fuel is of an undetermined and more or less variable character.

4. When supplied with gas under constant pressure, an acetylene flame of the type used in these experiments, that, namely, obtained by means of a burner composed of a single block of steatite, is more nearly constant in its intensity and color than any other flame with which I am acquainted, with the exception of that of the Hefner lamp. It is indeed questionable whether the latter is superior to acetylene in this respect and its comparative weakness in the blue and violet renders it very undesirable as a comparison source in spectrophotometry.

Method of Checking the Constancy of the Acetylene Flame.

To secure as complete a check as possible upon the constancy of the flame the following method, based upon the assumption that so long as the radiation from the flame remained constant, its light-giving power would not vary, was employed. A diaphragm d (Fig. 6) similar to that interposed between the slit and the flame and having an aperture of the same size, was mounted on the opposite side of the latter and a thermopile p was placed at a distance of about 15 cm. from this opening. A second diaphragm d', with an intervening air space served to cut off, in large part, the radiation

from the heated metal. Two thin sheets of glass forming the sides of an empty glass cell c of the kind used in the study of absorption spectra, etc., were placed between the cone of the thermopile and the second diaphragm; so that only those rays from the flame which were transmitted by the glass fell upon the face of the pile.

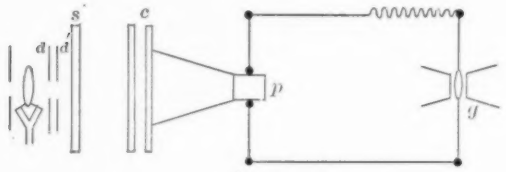


Fig. 6.

The thermopile was connected with a sensitive d'Arsonval galvanometer (g), the circuit being kept permanently closed, and a double metallic shutter s, which could be raised or lowered so as to open or close the opening in the diaphragm next to the flame was so mounted that it could be readily operated by an observer at the telescope of the galvanometer. When a reading of the radiation from the flame was to be made, the zero point of the galvanometer was noted and this shutter was raised during the short interval of time necessary to bring the needle, which was not strongly damped, to its first turning point. The shutter was immediately closed in order to prevent further heating of the face of the thermopile. This throw of the galvanometer was taken as an indication of the intensity of the flame. It was found that the thermopile would cool sufficiently within two minutes to admit of the repetition of the reading. These observations were taken by an assistant simultaneously with each setting of the spectrophotometer, the intention being to reject any spectrophotometric readings made at a time when the flame showed marked deviation from its standard intensity, and to reduce the readings to a uniform flame intensity under the assumption that for the small range of variation occurring from reading to reading, the changes in the brightness of the flame would be proportional to the variations of this galvanometer reading from the mean of the whole set. In point of fact it was found that the flame rarely varied by more than two per cent. from the mean in the course of a set of observations and remained most of the time within one per cent. From day to day its intensity was usually within the limits stated above although occasionally a larger variation was detected. None

of these variations in the course of the present investigation reached values so great as to lead me to hesitate to apply the correction already referred to, and all the observations described in this paper have been reduced to a constant flame intensity by means of a correction factor obtained from the readings of the galvanometer.

Control and Measurement of the Temperature of the Carbon Rod.

The carbon rod having been brought to the desired degree of incandescence by means of the current from a storage battery, was held at a constant temperature by varying the resistance placed in the battery circuit. The indications of the thermo-element inserted in the rod were noted by means of a potentiometer consisting of an accurately adjusted resistance box of 100,000 ohms, the smallest coils in which contained one ohm each, a sensitive galvanometer of the d'Arsonval type and a large Clark cell of the old Feussner type, against which the electro-motive force of the thermo-element was balanced in the usual manner. The arrangement of this potentiometer has been described in my recent paper[1] on the temperature of the acetylene flame. The cells used in the measurement of the temperature of the carbon rod were the same as those employed in that investigation and the same precautions were taken to preserve constancy of temperature and to control and check their electro-motive force. It was found that at the temperature of 18°, which was very closely the mean temperature of the room, the electro-motive force of the Feussner cells was 1.430 volts.

The potentiometer having been balanced by looping the circuit containing the thermo-element around a sufficient portion of the resistance box to balance its current against that of the Clark cells, a condition which was indicated by the reduction of the galvanometer deflection to zero, the current was maintained at such a value as to hold the carbon at a constant temperature during the time necessary to complete measurements of the intensity of eight different portions of the spectrum, ranging from the extreme red to the violet, with the corresponding portions of the spectrum of the acetylene flame. In order to insure the maintenance of this con-

[1] Nichols, Physical Review, 10, p. 237 (1900).

stant temperature in the rod, an assistant made repeated observations with the potentiometer and readjusted the resistance in the battery circuit whenever necessary. Excepting at very high temperatures where the rod was subject to rapid disintegration, it was rarely necessary to make any adjustment during the progress of a single set of observations. Readings of the current flowing through the carbon and of the fall of potential between its ends were made at the beginning and end of each experiment.

MAGNETIZATION OF IRON, STEEL, AND NICKEL WIRES BY INTERMITTENT CURRENT.

By K. Honda and S. Shimizu.

§ 1. Since Helmholtz first brought in question, about 50 years ago, whether the magnetization follows very rapid changes of magnetic force or not, several physicists have studied the same subject in different ways. Their results and criticisms are placed in a good order in the introduction to Wien's paper,[1] so that there is no need of repeating them.

In the paper above cited, Wien describes his own investigations on this point by elaborate experiments, and reconciles several apparent discrepancies, which exist in the results obtained by former observers. According to him, magnetic induction is always less in the alternate than in the constant field; the difference becomes greater and greater as the frequency increases. But the area of the hysteresis curve is always greater in the alternate than in the constant field, except when it is not very weak, in which the contrary is the case. The area also increases with the frequency. Whence he concludes that the magnetization cannot follow very rapid changes of the magnetic force.

Apart from the methods previously used, the following simple plan may conveniently be used to study the same question in its somewhat different aspect. Instead of using an alternate current, iron or nickel wire is magnetized by an intermittent current of definite frequency, and its mean intensity of magnetization is measured by the magnetometric method. The comparison of the intensity of magnetization corresponding to different frequencies will decide the proposed question.

§ 2. The apparatus for producing the intermittent current is the Pupin's interruptor. The copper or aluminum wire is stretched

[1] Wied. Ann., 66, 859, 1898.

horizontally, as shown in Fig. a, one of the ends is fixed to a stout support S, while the other, passing over a small metallic pulley P, is attached to a weight Q. Near the center, a short initial wire R is dipped into a mercury cup, in which the circuit is made or broken

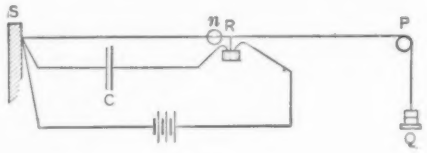


Fig. a.

in regular succession by the vibrating string. The string is maintained continuously oscillating by a magnet n, which may be either a permanent one or an electromagnet. A condenser C, whose capacity is one microfarad is connected to two sides of the mercury contact. The number of frequency is calculated from the formula

$$n = \frac{1}{2l}\sqrt{\frac{T}{\rho}},$$

where l, T, ρ denote respectively the length, the tension and the linear density of the string.

The mean intensity of the current is measured by a Thomson graded galvanometer which is from time to time compared with a deciampere balance. The magnetometer consists of a small bell magnet suspended in a thick copper case by a fine quartz fiber, the period of vibration being about 3 seconds. It is placed due magnetic east of the magnetizing coil, and its deflection is read by means of scales and telescope. The magnetizing coil is 34.8 cm. long and its frame is made of wood. It is wound in 4 layers with copper wire of about 2 mm. diameter; the field at the center of the coil due to a current of one ampere is 19.38 C.G.S. units. The coefficient of self-induction of the whole circuit is 2.35×10^7 cm. and its resistance 19.3 ohms, so that the time of relaxation is 0.00122 seconds.

§ 3. The method of observation is as follows: In the first place, the magnetizing coil, the magnetometer and a compensating coil are carefully placed in a line perpendicular to the magnetic meridian. A constant or intermittent current is sent through these coils and

the perfect compensation obtained by displacing the auxiliary coil in its axial line; then the current is reversed and the compensation tested, till there is no deflection by passing the current in either direction. The wire to be tested is then placed in the axial line of the coil, and magnetized in one direction and then in the other. If, on both sides, the corresponding deflections of the magnetometer are not numerically equal, the above process is repeated, till the compensation is perfect and the deflections of the magnetometer due to the magnetized wire alone are equal in two directions. Since the distance of the magnetometer from the nearer end of the magnetizing coil was only 21 cm., the adjustment was no easy task. When the adjustment is finished, the wire to be tested is demagnetized by reversals. The gradually increasing intermittent current of definite frequency is then passed through the magnetizing coil, and the corresponding deflections are noted, when they become stationary.

The deflection of the galvanometer or of the magnetometer was generally as steady as that due to steady current. It, therefore, represents the mean of the current or of the intensity of magnetization during the complete period of the intermittent current.

Owing to the smallness of the coefficient of self-induction compared with the resistance of the circuit, the deflection of the galvanometer due to stationary current was reduced to nearly half its original value, when the same current became intermittent with the frequency of 49 per second. When the frequency was increased, the spark gap remaining unaltered, the mean intensity of the current generally became a little greater. Hence in order that the deflection with the intermittent current may just be half that due to the steady one, the length of the spark gap had always to be increased slightly by an adjusting screw.

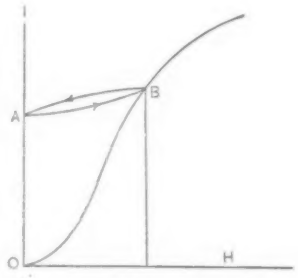


Fig. b.

The deflection of the magnetometer represents the mean intensity of magnetization during the complete period; but in the statical cycle between zero and a certain field, and perhaps in the cycle with intermittent current, the form of the hysteresis curve is a very elongated loop AB, as shown in Fig. b.

Let the extreme values of the intensities of magnetization be denoted by I_0 and I_1 respectively, and the intermediate value by I; the deflection of the magnetometer will be proportional to

$$\frac{1}{T}\int_0^T I dt.$$

In the evaluation of the integral, we may, with tolerable accuracy, put $I = I_0 + KH$, where K is a constant; hence

$$\frac{1}{T}\int_0^T I dt = I_0 + \frac{K}{T}\int_0^T H dt.$$

But in our experiments, the mean intensity of the intermittent current was always so adjusted, that it is just half of the intensity of the steady current; hence if H_1 be the corresponding field due to the steady current,

$$\frac{1}{2}H_1 = \frac{1}{T}\int_0^T H dt,$$

and therefore

$$\frac{1}{T}\int_0^T I dt = \frac{I_0 + I_1}{2}.$$

Hence the mean intensity of magnetization during the complete period is nearly the same as the arithmetical mean of the maximum intensity and the residual ones. This was also experimentally confirmed with the intermittent current of the frequency of 49 per second.

Though the increase of the mean intensity of magnetization does not necessarily imply that of the extreme intensity of magnetization for a given cycle, yet the experimental fact, hereafter to be described, teaches us that the change of the mean intensity of magnetization with the frequency is nearly the same amount as that of the actual intensity.

§ 4. The specimen tested had the following dimensions:

Metal.	Length.	Diameter.	Volume.	Density.
Wolfram steel.	21.00 cm.	0.135 cm.	0.302 ccm.	7.90
Soft iron.	21.00	0.135	0.302	7.80
Nickel.	21.07	0.134	0.299	8.95

The measurement of the magnetization of each of these ferromagnetics by steady current gave the following results expressed in *C.G.S.* units.

Wolfram-steel.		Soft iron.		Nickel.	
H	*I*	*H*	*I*	*H*	*I*
6.3	46	1.5	52	1.7	27
11.4	123	2.1	92	3.6	111
13.3	235	3.6	328	6.7	228
15.0	371	4.6	579	13.3	316
16.4	564	6.1	684	19.1	357
18.3	719	8.1	839	28.6	394
25.2	951	12.6	975	39.3	419
40.2	1121	23.5	1124	50.7	439
59.3	1212	51.5	1260	58.1	448

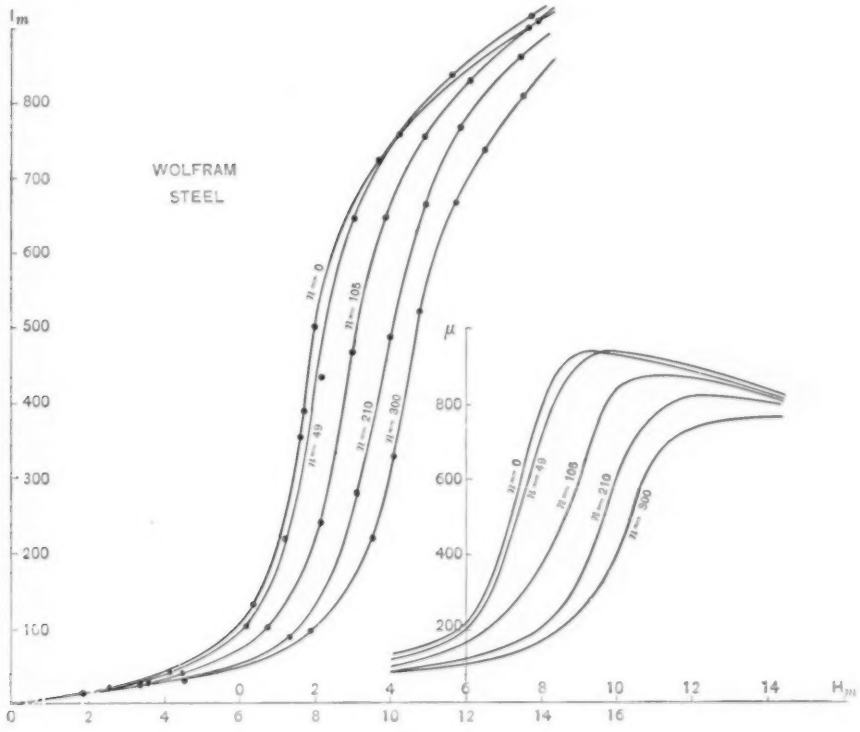


Fig. 1.

§5. The magnetization of Wolfram-steel with intermittent current of different frequencies is given in Fig. 1.

Here I_m denotes the apparent or mean intensity of magnetization, H_m the mean of the external field, the extreme field being always double its mean value, and n the frequency of the intermittent current. The curve corresponding to $n = 0$, which nearly coincides with the curve for $n = 49$, is one representing the arithmetical mean of the two intensities of magnetization, when the current is on and off.

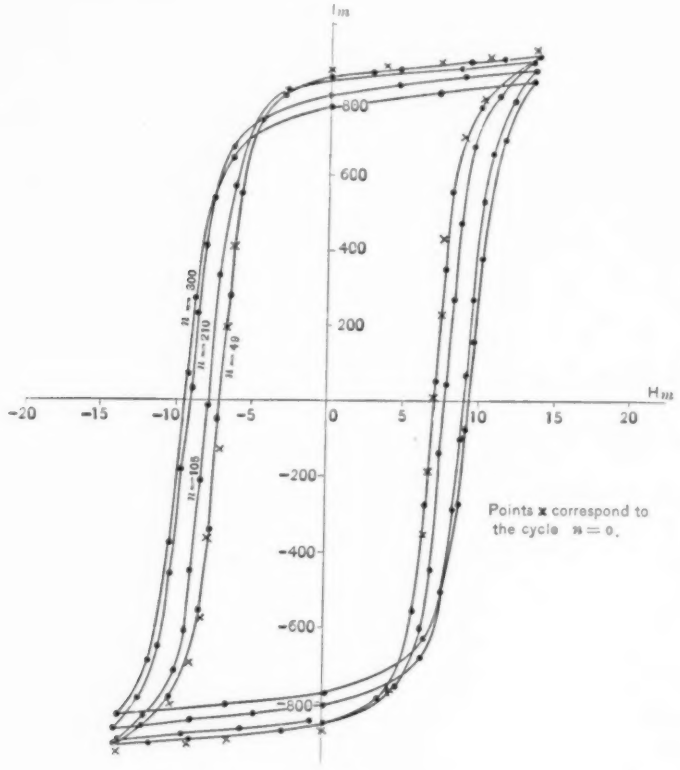


Fig. 2.

From these curves, we see that the mean intensity of magnetization decreases as the frequency increases. For a definite frequency, the difference becomes greater as the field increases, and attains its maximum value in a field near that of the maximum permeability. It then gradually decreases as the field is further increased.

The curves of the apparent value of permeability are also drawn in the same figure. It will be seen that the apparent value of per-

meability tends to a constant value as the frequency is increased, a fact which plays an important part in the theory of electric oscillation.

In the hysteresis cycle, the extreme value of magnetic induction becomes a little smaller, but the coercive force is greater than that for the statical cycle, so that the area of the hysteresis curve increases with the frequency, till it reaches a maximum and then decreases, as shown in Fig. 2.

The measurement of the areas of hysteresis curves with a planimeter gave the following results :

Frequency.	$n = 0$	$n = 105$	$n = 210$	$n = 300$
Apparent dissipated energy.	25600	27260	30120	29540

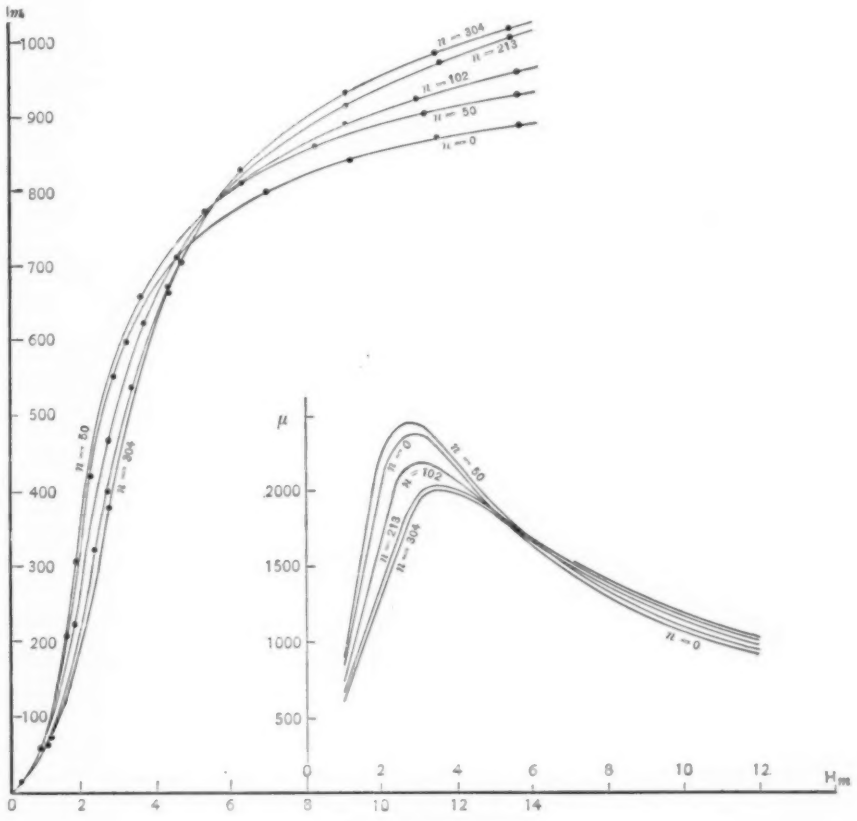


Fig. 3. Soft Iron.

In the form of the hysteresis curves, we notice that the portions of the curves lying between the maximum and zero fields are nearly parallel to each other; and as we have remarked, the apparent intensity of magnetization represents the mean of the extreme and residual intensities of magnetization. Hence it is evident from these two facts that the change in the intensity of magnetization by intermittent current is nearly of the same amount as that of the actual intensity of magnetization, as we have already remarked. Hence if we consider the apparent intensity to represent the extreme intensity of magnetization, the above results exactly coincide with those of Wien with alternate field.

§ 6. The results for soft iron and nickel are given in the following Figs. 3 and 4:

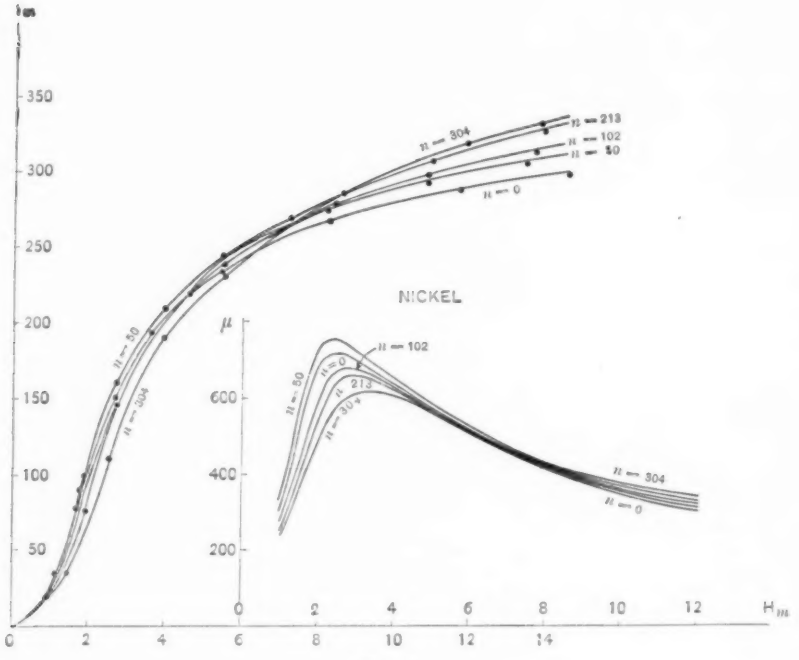


Fig. 4.

From these figures, we see that the nature of the change in low fields is exactly the same as for wolfram-steel, but the amount of the change is smaller than that for the steel. In stronger fields the

increase of the intensity of magnetization with the frequency is observed. Wien did not notice this reversal of the change of magnetization. It will also be noticed that the curve $n = 50$ for iron and nickel cuts in very low fields the curve $n = 0$. In strict sense, however, the curve $n = 0$ can not be compared with the others, because in drawing the curve, the arithmetical mean of two intensities of magnetization, when the current is on and off, is taken as the intensity of magnetization, and one half of the corresponding field as the field of magnetization.

In the hysteresis cycle for iron and nickel, the extreme intensity of magnetization and the coercive force for intermittent current are both greater than those due to steady current, and the area of the hysteresis cycle increases with the frequency, a fact which is in accordance with Wien's results. This is shown in the following table:

Frequency.	$n = 0$	$n = 107$	$n = 213$	$n = 304$
Apparent dissipated energy for iron.	5325	5520	6340	6625
Apparent dissipated energy for nickel.	1931	2029	2183	2336

§ 7. The summary of these results runs as follows:

1. For iron, steel and nickel wires, the magnetization in weak fields decreases as the frequency of the intermittent current is increased. On the contrary, the magnetization in stronger fields increases with the frequency.

2. The diminution of magnetization by a definite frequency of the intermittent current becomes greater as the field is increased, till it reaches a maximum in a field near that of the maximum permeability; it then gradually goes on decreasing and continues in that state, till there is increase in the stronger intermittent field.

3. The field, in which the change of magnetization vanishes increases with the frequency.

4. The area of the hysteresis curve for the maximum field of 27.7 C.G.S. units increases with the frequency; it reaches a maxi-

mum and then gradually decreases. As regards the explanation of these facts, it only suffices to assume with Wien that the magnetization has inertia.

It is well known that, when the frequency is very small, the extremities of the ordinates of the maximum intensity of magnetization by a gradually increasing intermittent current lie almost on the statical hysteresis curve between the same extreme fields. It is highly probable that at least within the range of the frequency used in the present experiment, the above result holds good. If this be true, the present experiment with intermittent current measures the same thing as that of Wien with alternate current. The remarkable coincidence between his and our results seems to justify the supposition. If he pushed his experiments to a still stronger field, it seems quite likely that he would have reached such a place, where the change of magnetization begins to increase with the frequency of the alternate current.

PHYSICAL LABORATORY, IMPERIAL UNIVERSITY,
TOKYO, JAPAN. March 26, 1901.

THE SPECIFIC HEAT OF SOLUTIONS WHICH ARE NOT ELECTROLYTES. II.

By William Francis Magie.

1. This paper is a continuation of one published under the same title in this Review, Vol. IX., No. 2, August, 1899. It presents several series of specific heats of non-electrolytes in solution, which furnish further confirmation of the law developed in that paper, but it is especially concerned with the examination of the questions: (1) whether the molecular heats of isomers in solution are always equal to each other; and (2) whether the molecular heat of a substance dissolved in different solvents is invariable or differs in the different solvents.

2. The calorimeter employed was essentially the same as that described in connection with the earlier part of the work. Various sources of error or of inconvenience were detected in it during the progress of the investigation, and, to avoid these, certain changes were made in the details of its construction. The evaporation of the liquids in the calorimeter vessels was a most important cause of the irregularities which appeared in a series of determinations. The heat of vaporization of the solvent is so great in comparison with its specific heat that even very slight differences in the rate of evaporation from the two vessels are sufficient to introduce serious irregularities. To avoid this the calorimeter vessels were furnished with covers, to which the resistance coils were attached. The stirring was effected by rotating paddles borne by the covers. This arrangement considerably reduces the probable error of each determination, and further relieves the observer of the necessity of weighing and refilling the vessels after each experiment.

The paraffine coating which was used in the earlier work to protect the resistance coils against electrolytic action was often ineffective, and the results of many observations had to be rejected

because of changes in the resistances. After many trials a satisfactory insulation was obtained by coating the coils first with asphalt varnish and then with ozokerite. Neither substance could be used alone, the varnish because it flaked off too readily and did not resist alcohol, the ozokerite, because it did not distribute itself well over the coils; but the double layer gave a tough and durable coating, which has protected the resistances perfectly since it was first applied.

Certain other sources of small errors were removed either by attention to the construction of the instruments or by the adoption of a definite procedure in making the observations. It is not necessary to go further into the consideration of this matter here. I am constructing a new instrument in a form which will embody such improvements as I have made, and shall take another opportunity to describe its operation and to exhibit the results which may be obtained with it.

3. The thermometers used were made for this work by Fuess. They are of Jena glass, No. 59, III., and are similar in size and shape. The graduation extends from 12° to about 34°, and each degree is divided directly into fiftieths. The reading microscopes are borne on the stems of the thermometers and are furnished with pointers which mark the center of the field of view, so that, by bringing the image of the mercury column between them, parallax is avoided, and a reading can be made by estimation to the thousandth of a degree. The thermometers were carefully compared with each other under the conditions of service.

4. *Cane Sugar in Water.*—By way of confirmation of the results for cane sugar obtained in my earlier work by a less accurate instrument, a test of this solute in a solution for which $N = 300$ was made, with the result that the value of ζ, the molecular heat, was determined as 153.6. Combining this value with those given in the former paper (§ 17), the mean value of ζ becomes 152.8.[1] This new value does not materially change the calculated specific heats.

5. *Dextrose with Water of Crystallization in Water.*—In order to deal with certain of the isomers of cane sugar, it is necessary to know

[1] By a misprint, the value of ζ for $N = 150$ is given in the former paper as 150; it should be 152.

how the water of crystallization, which they contain, shall be reckoned in when the solution is made up. To test this matter I examined dextrose, which can be prepared either with or without a molecule of water of crystallization. A solution of dextrose containing water of crystallization was made up with $N = 250$, on the supposition that the water of crystallization leaves the dextrose when it dissolves and becomes a part of the solvent. The value of the molecular heat obtained with this solution was 78.9. This is in perfect agreement with the mean molecular heat given for dextrose without water of crystallization in my former paper (§ 18), and justifies the supposition on which the solution was made up.

6. *Maltose in Water.*—The maltose was obtained from Kahlbaum. The solution was made up on the supposition that the water of crystallization becomes part of the solvent.

Maltose ($C_{12}H_{22}O_{11}+H_2O$) *in Water. Molecular Weight*, 342.

N	s' Observed.	s' Calculated.	ζ
300	0.9657	0.9653	145
400	0.9735	0.9735	142
445.4	0.9760	0.9762	141
	Mean molecular heat.		142.7

7. *Milk Sugar in Water.*—The milk sugar was obtained from Merck. It was sufficiently dry and pure to be used directly. The solutions were made up on the supposition that the water of crystallization becomes a part of the solvent.

The first trials with the solution for which $N = 200$ showed an apparent progressive change in the specific heat of the solution and therefore in the molecular heat of the solute. This change could not be traced to any failure of the calorimeter, and repetitions of the test with fresh solutions proved that it was really due to the properties of the solution. Three sets of determinations were made, of which the results are given in the following table. The numbers given are the apparent molecular heats obtained at intervals of about 25 minutes. They are arranged so as to bring the numbers corresponding to the same condition of the solution in the same horizontal row.

Milk Sugar in Water. Successive Values of ζ at **25-minute** *Intervals.*

I.	II.	III.	Means.
	147	148	147
135	139	139	138
143	143	147	144
146	148	148	147
149	151	148	149
		151	151
		153	153
		150	150
		146	
		150	
		151	

Solution II. was tested after 2 days and gave a constant molecular heat, 144; and after 13 days it gave again a constant molecular heat, 146. A solution of the same strength which was made up in boiling water and tested after 3 days gave also the constant molecular heat, 146.

A solution of milk sugar for which $N = 300$, made up with cold water, showed no changes in the molecular heats except such as might easily be due to the errors of observation. The molecular heat obtained for it was 155. A similar solution made up in boiling water gave the constant molecular heat, 154; but tested after 2 days it gave the constant molecular heat, 144. Apparently the molecular heat reaches its maximum value more speedily in the more dilute solution. The condition reached after the lapse of considerable time may be considered the true and final condition of the solution. For this condition the results are as follows:

Milk Sugar ($C_{12}H_{22}O_{11} + H_2O$) in Water. Molecular Weight, **342.**

N.	s' Observed.	s' Calculated.	ζ
200	0.9501	0.9499	145
300	0.9656	0.9656	144
	Mean molecular heat.		144.5

It has been shown[1] that the rotatory power of a solution of milk sugar in water for polarized light changes gradually after the solu-

[1] Erdmann, Berliner Ber., 13, p. 2180.

tion is made up until after about seven hours it attains a value which remains constant from that time on. This phenomenon is not accompanied by any perceptible temperature changes. Erdmann ascribes it to the gradual formation of an allotropic modification of the milk sugar in the solution, a modification which cannot exist in the dry state. In the light of this evidence for molecular changes in the solution we may ascribe the changes in the molecular heat to the changing form of the molecules and to the consequent changes in the restraints to which their various parts are subjected.

Erdmann found that when the solution is boiled for a short time it shows at once the final value of the rotatory power. To see if boiling would produce a similar effect on the molecular heats two trials were made with solutions in which $N = 200$, made up in boiling water and boiled for five minutes. In both trials the molecular heats showed variable values, beginning with about 145 and increasing gradually to 155 or more. One of these solutions when tested after 3 days gave the constant value 146.

8. *Levulose in Water.*—The levulose used in the two more dilute solutions was obtained from Kahlbaum, in the form of "large and beautiful formed crystals, which were transparent and exhibited the smallest trace of straw color. These crystals were permanent in the air."[1]

The powdered levulose had been kept for a year in a stoppered bottle, and when exposed over sulphuric acid for two days, it showed a slight loss in weight, less than one part in a thousand. It was then assumed to be dry. The most concentrated solution was made from the ordinary form of levulose, and its exact concentration was determined from its specific gravity.

Levulose ($C_6H_{12}O_6$) *in Water. Molecular Weight,* 180.

N	s' Observed.	s' Calculated.	ζ
201.5	0.9761	0.9763	89
300	0.9837	0.9838	88.8
400	0.9880	0.9878	91.2
Mean molecular heat.			89.6

[1] Loomis, PHYS. REV., Vol. XII., No. 4, April, 1901

9. *Mannite in Water.*—In the former paper the values given for the molecular heat of mannite in water were not constant. It was there stated that the probable value for the molecular heat was about 108, the value obtained for the solution for which $N = 400$, and that the other values were in error. I have redetermined the specific heats for solutions of mannite, with the following results:

Mannite ($C_6H_{14}O_6$) *in Water. Molecular Weight*, 182.

N	s' Observed.	s' Calculated.	ζ
107.8	0.9658	0.9651	109.2
200	0.9806	0.9804	108.6
400	0.9900	0.9900	108
500	0.9917	0.9919	106
Mean molecular heat.			108

In this table the result of the earlier work for $N = 400$ is included, which was not affected by the circumstances to which the erroneous values for the other concentrations were due.

10. *Dulcite in Water.*—The dulcite used was obtained from Kahlbaum, and was assumed to be pure. It dissolves with difficulty and only dilute solutions were used.

Dulcite ($C_6H_{14}O_6$) *in Water. Molecular Weight*, 182.

N	s' Observed.	s' Calculated.	ζ
400	0.9883	0.9885	96
500	0.9910	0.9908	99
Mean molecular heat.			97.5

11. The isomers resorcin, hydroquinone and pyrocatechin were chosen for special investigation because they could be obtained from the chemists in reasonable purity, and because they dissolve in alcohol as well as in water. When their molecular heats are the same within the limits of probable error they will be combined to give the mean molecular heat and the calculated specific heats will be those determined from this mean.

12. *Resorcin and Hydroquinone in Water.*

Resorcin ($C_6H_6O_2$) *in Water. Molecular Weight*, 110.

N	s' Observed.	s' Calculated.	ζ
300	0.9916	0.9915	64
400	0.9936	0.9936	63

Hydroquinone ($C_6H_6O_2$) *in Water.*

N	s' Observed.	s' Calculated.	ζ
300	0.9915	0.9915	63.4
400	0.9936	0.9936	63.2
Mean molecular heat.			63.4

13. *Pyrocatechin in Water.*

Pyrocatechin ($C_6H_6O_2$) *in Water. Molecular Weight*, 110.

N	s' Observed.	s' Calculated.	ζ
300	0.9937	0.9938	75
400	0.9953	0.9952	76
Mean molecular heat.			75.5

14. *Resorcin, Hydroquinone, and Pyrocatechin in Alcohol.*—The alcohol used in these solutions was an ordinary good commercial alcohol, with a specific gravity about 0.815, and containing about 10 per cent. of water. The specific heat of alcohol containing 10 per cent. of water is given by Dupré and Page[1] as 0.6576, and this value was accordingly taken as the specific heat of the solvent. This value cannot be so far wrong as to affect the conclusions which are drawn from the results.

In these cases, where the solvent has no definite constitution, the specific heats themselves have no interest. I shall therefore give only the molecular heats, determined for two concentrations, which nearly correspond, in respect to the volume occupied by one gram-

[1] Phil. Trans., 1869; Pogg. Ann., Ergänzungsband V., p. 21.

molecule of the solute, to the solutions with water in which $N = 300$, and $N = 400$. These concentrations are designated respectively by I and II.

Molecular Heats in Alcohol.

	I	II	Means.
Resorcin.	58.3	55.2	56.7
Hydroquinone.	56.1	57.3	56.7
Pyrocatechin.	57.6	56.6	57.1

15. *Phenol in Water and in Alcohol.*—The phenol used was obtained from Merck. It was sufficiently pure for the tests made upon it. Its molecular heat determined in water, in a solution for which $N = 300$, was 71.5. In an alcoholic solution, in which the volume occupied by the phenol was very nearly that which it occupied in the aqueous solution, the molecular heat was 51.4. In accordance with what might be expected from its formula, C_6H_6O, its molecular weight, 94, and its nature, it shows a marked resemblance to the three isomers just considered. Its behavior is analogous to that of pyrocatechin.

16. In commenting on these results, attention may be directed first to the general confirmation afforded by them of the theory developed in the earlier paper. The molecular heats are constant for different concentrations when the solutions are so dilute that the assumptions of the theory apply to them. This is true even in the case of the alcoholic solutions, although other alcoholic solutions do not obey this law. In all these cases, therefore, the osmotic pressure is directly proportional to the absolute temperature. In several of these solutions Loomis[1] has shown that the depressions of the freezing temperature indicate a certain degree of association among the molecules of the solute. The constancy of the molecular heats obtained with different concentrations for these solutions shows that this association is not noticeably changed by a change of temperature.

A word may be said about the range of concentration through which the molecular heats are constant. In my experiments, in different cases, this runs from about the concentration of a "normal"

[1] PHYSICAL REVIEW, Vol. XII., No. 4, April, 1901.

solution to that of a "tenth-normal," as used in the determination of electrical conductivities and of freezing temperatures. For such concentrations the study of the depression of the freezing temperature indicates that the osmotic pressure of the solution does not accurately conform to Boyle's law. On the other hand, the constancy of the molecular heats indicates that the osmotic pressure does conform to Gay-Lussac's law. These relations are perfectly comparable with those exhibited by gases under pressure, for which Boyle's law is never more than an approximate statement of the relations between pressure and volume, while the ratio between the pressure and the absolute temperature is very closely a constant.

17. It is evident, secondly, that the molecular heats of isomers in solution in the same solvent are not always the same. Thus the molecular heats of maltose and of milk sugar in its final condition are nearly the same, but differ from the molecular heat of cane sugar. The maximum molecular heat attained for milk sugar during its period of change is the same or nearly the same as that of cane sugar, but differs from that of maltose. The molecular heats of dextrose and levulose differ considerably, as do also those of mannite and dulcite. The molecular heats of resorcin and hydroquinone in water are the same, but differ from that of pyrocatechin. On the other hand, the molecular heats of all three of these substances in alcohol are the same. These solutions, therefore, furnish another illustration of the impossibility of representing the molecular heats of compounds by sums of constant atomic heats of their constituent atoms.

18. It is possible to obtain these molecular heats, at least to a fairly close approximation, in the way proposed by K. Puschl,[1] by assigning to each atom one of the numbers 12, 6, 3, 1.5, 0.75 ; but the perfectly arbitrary way in which the numbers assigned to any one element differ in the different compounds deprives them of any physical significance.

19. The only way, I think, to explain the values of these molecular heats is to refer them, in general terms, to the degrees of freedom introduced by the solute into the solution. A very ingenious, and in many respects successful attempt has been made by

[1] Beiblätter, Bd. 24, No. 10, p. 1103.

Staigmüller[1] to calculate the specific heats of the gases from plausible hypotheses as to the degrees of freedom of their molecules; but no such calculation can be made with these substances, partly because of the complexity of their molecules, which makes an estimate of their degrees of freedom impossible, and partly because there is no reason to think that the molecular heats determined for them in solution are due entirely to their own molecular structure and not rather to a more complicated structure containing in one group a molecule of the solute and one or more molecules of the solvent. By supposing the molecular heats to be due only to the molecules of the solute, it is possible to calculate from them by Staigmüller's formulas the degrees of freedom of the molecules of the different substances examined. Certain curious and at first sight promising relations appear among the degrees of freedom thus calculated, and it is possible to reproduce them, in at least two different schemes, by assigning a certain number of degrees of freedom, not exceeding three, to the atoms of each element in the molecule. Notwithstanding a very considerable regularity in the numbers assigned to the elements in the different compounds and marked analogies which appear between the sets of numbers assigned to the isomers and to compounds of generally similar character, I am forced, for the reasons just adduced, to reject all such schemes for the present as illusory or at least as impossible of proof.

20. It is evident, thirdly, that the apparent molecular heats of the same solute differ in different solvents. It is, therefore, inadmissible to consider the process of solution as the mere passage of the molecules of solute into a state in every way equivalent to the gaseous state. The solvent must interact with the solute, so as either to change the structure and the number of degrees of freedom of the solute or to experience a change in its own structure and the number of its degrees of freedom.

21. The specific heats of electrolytic solutions confirm the conclusion that there is an interaction between the solute and the solvent, and indicate that for such solutions, at least, the solvent is itself affected by the presence of the solute. It was shown by Thomsen[2] that the specific heats of aqueous solutions of electro-

[1] Wied. Ann., Vol. 65, 1898, p. 655.
[2] Pogg. Ann., 142, p. 337, 1871.

lytes are in general lower than those which would be expected if the heat capacities of such solutions were the sums of the heat capacities of their constituents. Indeed, in most cases the apparent molecular heats of the solutes, calculated on the hypothesis that the molecular heat of the solvent remains constant, become negative with increasing dilution. It is plainly inadmissible to assign negative specific heats to the solutes or to any part of them, and we are forced to assume that the specific heat of the solvent or of a part of it is diminished by the presence of the solute. I shall postpone a full discussion of this matter to some future time, when the experimental data are more complete. It will be sufficient at present to state that by proceeding on a particular form of this assumption, we are led to a formula for the heat capacity C of an electrolytic solution of the form

$$C = H + A - pB,$$

in which H is the original heat capacity of the solvent, p is the dissociation factor, or the ratio of the mass of the solute which is dissociated to the whole mass of the solute, and A and B are constants to be determined from the observed heat capacities. This formula applied to the solutions examined by Thomsen, gives a very exact reproduction of the heat capacities found by him for different concentrations. The agreement is so complete as to leave little doubt that the hypothesis upon which it is obtained is justified.[1]

[1] Paper read before American Physical Society, April 27, 1901; Bulletin of Am. Phys. Society.

POLARIZATION AND INTERNAL RESISTANCE OF ELECTROLYTIC CELLS. I.

BY MARTIN D. ATKINS.

INTRODUCTORY NOTE ON THE POLARIZATION-CAPACITY OF ELECTROLYTIC CELLS.[1]

IT is well known that an electrolytic cell behaves like a condenser, or better, two condensers in series, a difference of potential being produced by the passage of a quantity of electricity. In general

$$c\frac{dp}{dt} = i$$

c is called the polarization capacity and is obviously a variable quantity becoming infinitely large after a certain maximum limit of polarization has been reached. On the other hand c has a definite value when the time t, during which the current is flowing is decreased to zero. This value seems to be of importance and is called the "initial capacity" or short "the polarization capacity" of a cell.

Apparently the polarization-capacity may be approximately determined by alternating current methods. Varley,[2] M. Wien,[3] Gordon,[4] Neumann[5] and many others have worked on this problem and though their results are not in absolute agreement, it may be asserted that every metal has a definite "initial polarization capacity" with electrolytic solutions. Concentration and temperature of solution have some influence upon its value, and here the different experimenters arrive at widely different results, a great many disturbing factors entering into the process. So far only small polarization capacities, principally Pt and Hg in H_2SO_4 have been measured.

By knowing the exact formula for polarization as a function of the time and determining the constants, we will be able to calculate the

[1] By K. E. Guthe.
[2] Proc. Roy. Soc., 1871.
[3] Wied. Ann., 58, p. 37, 1896.
[4] Wied. Ann., 61, p. 1, 1897.
[5] Wied. Ann., 1899.

capacity of a cell from these data. Wiedeburg has done so by making use of Bartoli's experiments on Pt in H_2SO_4 and found a result agreeing quite closely with Kohlrausch's direct results.

In a former paper[1] I have been able to show that Bartoli's empirical formula, being the same as one derived by Wiedeburg from a few theoretical suppositions, explains the apparent change of the internal resistance with different current densities, very often attributed to a "resistance of transition."

This formula has the simplified form

$$p = P(1 - e^{-aq}) \tag{1}$$

where P is a constant, "the maximum polarization," a a constant depending on the size of the electrodes and q the quantity of electricity having passed through the cell.

By a simple arrangement of the apparatus, namely by using an E.M.F. very large in comparison with P and using a large non-inductive resistance in series with the cell we were able to have a constant current through the cell during one observation, such that we could employ the formula

$$\rho I = rI + P(1 - e^{-KI}) \tag{2}$$

where ρ is the apparent and r the real resistance of the cell. In the paper mentioned I have shown that this formula represents the resistance curve obtained for Cu in $CuSO_4$.

The same method enables us to determine the polarization capacity of the electrolytic cell and this method is also very well applicable to cells of very large polarization capacities, as those of the so-called unpolarizable electrodes.

It follows from equation (1) that the polarization capacity is

$$c' = \frac{e^{aq}}{Pa}$$

and the initial capacity

$$c = \frac{1}{Pa}$$

or using formula (2)

$$c = \frac{t}{PK}.$$

[1] PHYS. REV., 7, p. 193, 1898.

From the values of P and K calculated from the curves and knowing the time t and the area of the electrodes we can easily determine the capacity of unit area of the electrodes.

I wish to correct a slight error, which occurs in my former paper. From equation (2) we see that for very large currents the apparent resistance equals the real resistance of the cell. For zero current $\rho - r = PK$, or the curve will cut the Y axis, on which the ρ's are plotted at a distance equal to PK above the real resistance.

We have therefore here *a constant current method* for finding the polarization capacity of an electrolytic cell, applicable also to large capacities, which cannot be determined by alternating current methods.

On the other hand all the disturbing influences, which have been found by other observers, will be noticeable here. This method may therefore be used to a great advantage in the study of the changes going on in an electrolytic cell.

It will also enable us to throw some light on peculiarities, observed in researches on the resistance of transition.

MICH. UNIV. PHYSICAL LABORATORY, June, 1899.

PART I. THEORY AND FORMULÆ.

Of the various theories, advanced in explanation of the phenomena observed in electrolytic cells, that of Wiedeburg[1] is deserving of attention in that it is expressed in mathematical formulæ, and that it explains, by polarization alone, those various changes, attending the passage of an electric current through a cell, which, by other theories, have been ascribed to causes as various as the theories themselves. An investigation of this theory becomes then one of extreme interest; since, should it be found to accord with the results of experiment, the question of what occurs within an electrolytic cell would be much simplified. An added interest has attached to this subject, since this investigation was begun, owing to the fact that Dr. Guthe has derived a formula, reducible to the exact form of that of Wiedeburg, from considering the polarization capacity alone. By making use of this derived formula and the hypothesis that the polarization capacity, for any given solution and electrodes, is constant, the method of this research becomes ap-

[1] Wiedeburg's Habilitationschrift, Leipzig, 1893. Wied. Ann., 51, 302, 1894.

plicable to the measurement of the polarization capacity of a given cell.[1] This assumption is in agreement with the experimental results of several investigators, among whom may be mentioned: Herwig, 1871; Blondlot, 1881; Kohlrausch, 1878; and others.

It was for the purpose of determining, if possible, the value of Wiedeburg's theory, and the application of the formulæ he derives, that this investigation was undertaken. It may be said to have had as its objective points the answering of these two questions: (*a*) "Is the change in the resistance of an electrolytic cell with varying current a real or an apparent change?" (*b*) "Does the Wiedeburg theory, with its derived formulæ, satisfy the known conditions, and the characteristic curves, of this change?"

In a preliminary paper,[2] making use of some of the first results of this research, Dr. Guthe has described the method employed and given a brief statement of the theory of Wiedeburg. In the interest of unity, however, these points may well be briefly treated here.

A statement of his fundamental hypotheses is given by Wiedeburg[3] as follows: "I assume that under all circumstances, even with extremely small electromotive forces, electrolysis occurs, viz: of such a nature that in general a part of the ions of the electrolyte, accumulating at the electrodes, is neutralized; *i. e.*, undergoes chemical transformation with loss of its electric charge. This neutralization advances with a variable rapidity, in accordance with a law very similar to that of ordinary chemical reaction. The more numerous are the unneutralized, polarizing ions, accumulated before the electrodes, the more rapidly the further accumulation diminishes with the time; and the more rapidly, on the other hand, the neutralization (electrolysis) proceeds. The increasing polarization would soon produce a cessation of the migration of the ions, for every E.M.F. below its maximum, were it not that other processes, not electric in their nature, operate constantly to decrease it; removing the ions, partly by transference to the interior of the electrodes

[1] Guthe and Atkins, Polarization and Polarization Capacity of Elect. Cells, Proceedings A. A. A. S., 1899, p. 109.

[2] Polarization and Internal Resistance of Electrolytic Cells: Guthe, PHYS. REV., Vol. VII., No. 38.

[3] "Zur Frage nach dem Grundgesetz der Elektrolyse," O. Wiedeburg, Zeit. Phys. Chem., XIV., I., 1894.

—occlusion—partly by union with neutral dissolved substances, *e. g.*, atmospheric oxygen. It is evident then that, even with an E.M.F. far less than a Daniell, by suitable arrangement of the apparatus, an actual electrolysis of 'acidulated water' may be brought about, increasing even to the point of the evolution of gas."

Let us now apply this theory to the simplest possible case, that of a metallic electrode in a solution of its own salt. If we pass through such a cell any current, of even the slightest E.M.F., the ions are swept to the respective electrodes, carrying their electric charges. Some of these ions pass at once to the electrodes, giving up to them their electricity, becoming themselves neutral and contributing nothing to the counter-electromotive force of polarization. Not all the charged ions however thus give up their electricity, some remaining heaped up before the electrodes. The difference in concentration thus produced results in the counter E.M.F. of polarization. The number of ions free at any instant, with any given solution and electrode, is proportional to the difference between the maximum concentration possible and that obtaining at the moment under consideration.

The formulæ derived from these suppositions by the author of this theory are the same as those of Bartoli[1] upon whose experiments they are founded, viz:

$$\text{(I.)} \qquad p = \frac{P_1}{2}(1 - e^{-\frac{\beta_1 q}{S_1}}) + \frac{P_2}{2}(1 - e^{-\frac{\beta_2 q}{S_2}}).$$

Here p is the momentary value of the polarization, whose maximum values are denoted by P_1 and P_2, for the respective electrodes; β_1 and β_2 are constants depending upon the electrodes. S_1 and S_2 denote the areas of the electrodes; and q the quantity of electricity that has passed through the cell.

In the case under consideration, since the electrodes are identical in kind and of equal areas, $\beta_1 = \beta_2$ and $S_1 = S_2$; and the formula simplifies to

$$\text{(II.)} \qquad p = P(1 - e^{-\beta q}).$$

If now we make the times of each discharge through the cell very

[1] Wied. Elektricitat, Vol. II., 883.

short, and the same for all currents, since $q = It$ (II.) reduces to

$$p = P(1 - e^{-\frac{\beta tI}{S}}).$$

Then for $\left(\frac{BtI}{S}\right)$ we may write KI, and equation (II.) becomes

(III.) $$p = P(1 - e^{-KI}).$$

Deriving the expression for the current in accordance with Ohm's law we obtain

(IV.) $$I = \frac{E' - P(1 - e^{-KI})}{r}.$$

Where E' is the applied E.M.F. at the terminals of the cell, and r its internal resistance. Upon the assumption that no polarization has occurred in the time of passing the current, the apparent internal resistance ρ is usually computed from the formula

(V.) $$\rho = \frac{E'}{I}$$

Substracting (IV.) from (V.) gives equation (VI.), another form of equation (IV.)

(VI.) $$\rho - r = \frac{P(1 - e^{-KI})}{I}.$$

Inspection of this equation shows that the apparent resistance, as usually found by methods taking no account of the polarization, is larger than the real resistance r, found by this method in accordance with Wiedeburg's theory. In every case where comparison could be made with results obtained by the Kohlrausch method, this condition has been fulfilled; while the method has the advantage of applicability to those cases in which the latter method could not be used. Further inspection of equation (VI.) shows that for very large currents, and small polarization, ρ, the apparent, becomes equal to r, the real, internal resistance; while, for zero current, $\rho - r = KP$.

If the apparatus be of such sort that the times for several series of observations can be maintained the same, we may form the following series of equations:

(VII.) $$\rho_1 - r_1 = \frac{P(1 - e^{-KI_1})}{I_1}$$

(VIII.) $$\rho_2 - r_2 = \frac{P(1 - e^{-KI_2})}{I_2}, \quad \text{etc.}$$

If now we assume $r_1 = r_2$ we obtain, by combining three observations, the following equations

(IX.) $$P = \frac{E_1 I_2 - E_2 I_1}{I_2(1 - e^{-KI_1}) - I_1(1 - e^{-KI_2})}$$

(X.) $$\frac{E_1 I_2 - E_2 I_1}{E_2 I_3 - E_3 I_2} = \frac{I_2(1 - e^{-KI_1}) - I_1(1 - e^{-KI_2})}{I_3(1 - e^{-KI_2}) - I_2(1 - e^{-KI_3})} = Q.$$

The values of E and I can be computed from the observed data and the quotient Q thus determined. K is then computed by successive substitutions until the assigned value satisfies the second member of the equation. In practice, usually, values were found for K which gave values for Q, lying near, but both above and below, the required value. By plotting a curve then, with the assigned value of K and resulting quotients, Q, the value required, could be taken from the curve. Equation (IX.) could then be solved for P. Evidently, were there nothing to indicate the region to be explored for the value of K, such a method, involving a large expenditure of time and a wearisome amount of computation, would be of little practical value. Fortunately it is possible to obtain at once, in most cases, approximate values for both K and P.

Inspection of equation (IX.) shows us that, in case of large currents, with K large, as it is when the electrodes are small, the factor $(1 - e^{-KI})$ is approximately equal to 1. If then we make use of observations taken with large currents, we may use equation (IX.) in this modified form.

(IX.^{a}) $$P = \frac{E_1 I_2 - E_2 I_1}{I_2 - I_1},$$ which gives us P at once.

There are then two methods for obtaining approximate values for K. (1) We may compute r for all currrents, beginning with the largest used, and taking an average from such values as do not largely differ. With this mean value, and the observations made with smallest currents, we may compute K from equation (VI.).

(VI.) $$\rho - r = \frac{P(1 - e^{-KI})}{I}$$

(2) From an observation with large current combined with one when the current is small we obtain

$$r = \frac{E_1 - P}{I_1} = \frac{E_2 - P(1 - e^{-KI_2})}{I_2}$$ which solved for K gives

$$\text{(XI.)} \qquad K = \frac{\log\left\{\dfrac{P}{\dfrac{I_2}{I_1}(E_1 - P) - (E_2 - P)}\right\}}{I_2 \log e}.$$

Having, by either of these methods, approximate values for K and P, the solution, by successive substitutions and the use of the curve, becomes less difficult. The latter of these methods was the one employed almost exclusively, in the second part of this investigation, in every case where K was sufficiently large to render it applicable.

It may be said in further explanation of the formulæ, that, with the high applied E.M.F.—from 66 to 82 volts—employed in these experiments, and the small values obtained for the polarization—in only one case exceeding 0.2 of a volt—the assumption that I in any case does not vary while the current is flowing is certainly correct to a degree far within the limits of negligible error.

The Apparatus and Method.

The apparatus used was the pendulum apparatus designed by Professor Henry L. Carhart[1] and the arrangement was that shown in the accompanying diagram (Fig. 1). The pendulum when released struck and overturned in order keys I. to IV., causing a current from the storage battery B, with an E.M.F. of from 66 to 82 volts, to flow through the electrolytic cell E during the passage of the pendulum between these points. When key II. was thrown by the pendulum in its passage the condenser K was charged at will—as determined by the commutator C—with either the difference of potential between the electrodes, or that between the terminals of the known resistance R. This resistance was made nearly equal to that

[1] Phys. Rev., II., 392, 1895; Carhart & Patterson, Elect. Measurements, p. 106.

of the cell under investigation, to eliminate possible errors which might arise from widely diverging deflections of the galvanometer. The condenser was discharged through the galvanometer G when key III. was overthrown. The condenser used was one which careful tests had found approximately free from leakage and absorption. The constant (102.1) for the ballistic galvanometer, had been many times carefully determined. Deflections were read from the image of an aperture and crosswire upon a ground-glass scale; and, by the use of reading lenses, could be easily determined to tenths of a scale

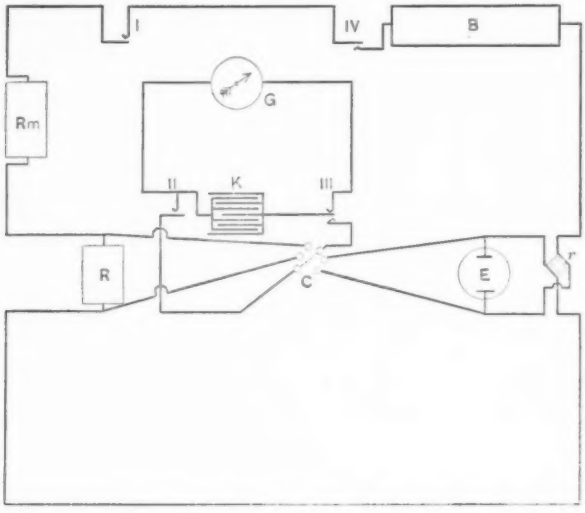


Fig. 1.

division. Later in the investigation, after the eye had become accustomed to the work, it was found possible to dispense with these lenses.

Several points of possible error, which suggested themselves, were the subjects of preliminary investigation. It was thought possible that, with the smallest currents used, there might be a loss in charging the condenser; or that it might not fully charge in the short interval allowed for this purpose. To determine the first of these points a key was placed in the galvanometer circuit. The pendulum was then allowed to swing, charging the condenser, but without

discharging it. It was then charged again and allowed to discharge as usual through the galvanometer. Readings, thus obtained, did not differ from those obtained by the single charging of the condenser. To determine the second point, the time of charging the condenser was varied largely, key II. being even placed before key I., so that the condenser was in circuit before the current began to flow. The results did not change. It was then evident that the condenser was fully charged, even by the smallest currents, and that there was no loss upon these currents within the condenser and its circuit.

To eliminate adventitious potential differences, either within the cell or condenser, keys, not shown in the diagram, were introduced, by means of which both were kept short-circuited until the instant of releasing the pendulum.

Although the current was allowed to flow for such short intervals, it was found that, with some cells, a marked polarization gradually established itself. To eliminate this, together with possible errors in the galvanometer, a reversing key, *r*, was introduced, by means of which the cell could be depolarized, or the readings tested, if desired.

A somewhat extended, though unsatisfactory, investigation, made early in the work, seemed to indicate that temperature changes had very little influence upon the nature of the curves obtained. An example of this is seen in the two curves for bright platinum electrodes (in H_2SO_4), shown in Plate III., No. 1. It will be seen that, with so great a difference in temperature as 17 degrees, the curves, reduced to the same resistance, are nearly identical. Although a further investigation of this question is intended, and necessary, before an authoritative statement can be made as to the effect of temperature upon the constants, it is quite certain that such small changes as may have occurred in the course of an investigation, rarely reaching 1.5 degrees, could have had no appreciable influence upon the results. Precautionary measures were always taken, by using large amounts of the solutions (from 2 to 10 liters), and by placing the cells in a constant temperature bath. By this means, also, irregularities due to variations in density, convection currents, etc., were reduced to a minimum.

PRELIMINARY INVESTIGATION OF $CuSO_4$ BETWEEN COPPER ELECTRODES.

Since in the preliminary investigation, already reported by Dr. Guthe, copper electrodes in a solution of $CuSO_4$ had been employed, with results in such seeming accord with the theory, the first step in this investigation was a repetition of the observations with these materials. Copper electrodes 10 × 13 cm. were used, insulated—as were all plates investigated—upon the back with a coating of beeswax. The solution was prepared by dissolving 25 grammes of C. P. copper sulphate in 1 liter of distilled water at 20°. It became very soon evident that the results obtained depended upon how long the electrodes had been in the solution. So an experiment was made to determine, if possible, the reasons for the irregularities observed. Successive observations were taken; one, immediately after placing the plates in the solution; another, after two and one-half hours; and a third, after twenty-four hours. The three curves, for the change in apparent resistance (ρ) with the current (I), are shown in Plate II., Fig. 1, Nos. I., II., III. Since it seemed probable that the great increase in apparent resistance was due to oxidation, it is of interest to note that, despite the great disparity in range of the three curves, they start at the same point; *i. e.*, the actual resistance r is the same in each case. This fact indicates that it is not really an increase in resistance, due to a badly conducting film of copper oxide, as has been said, but, rather, an effect due to polarization and its conditions. A possible explanation of this change will be given later, in the general discussion of the results. From the tables of results which follow, it may be seen that, while the first curve is well satisfied by our formulæ, the second is less, and the third still less, in agreement therewith.

The notation employed in these, as in all tables to be given hereafter, is the following: Cap., in the first column, denotes the capacity of the condenser in Micro-Farads; dC, the galvanometer deflection upon the cell; dR, the same upon the resistance. I signifies the current in ampères; ρ, the apparent resistance in ohms; r, the internal resistance computed according to the Wiedeburg formula; P, the maximum value of the polarization in volts; $(1 - e^{-KI})$, the correction factor.

To avoid the errors arising from taking small differences of values from observations lying adjacent, it has been the custom in all these computations to divide the observations into two groups, as has been done here, *e. g.*, P is computed from 1, 4; 2, 5; 3, 6 and 4, 7 respectively.

TABLE I.

I. Oxidation Curve, Cu in $CuSO_4$. Nov. 19. $T = 25.5°$; $R = 5$ *ohms. Electrodes* 10×13 *cm. Solution* 25 *G. in* 1 *L.* $K = 20$; $P = .056$; $KP = 1.12$.

Cap.	dC	dR	I	ρ	$(1-e^{-KI})$	r	P
0.1	176.3	160.3	.6200	5.50	1.0000	5.41	
0.2	187.5	168.0	.3291	5.58	.9983	5.41	
0.6	245.7	212.0	.1385	5.80	.9019	5.42	
1.0	212.8	177.0	.0693	6.01	.7395	5.42	.0564
"	108.5	87.0	.0341	6.24	.4829	5.44	.0589
"	44.5	35.0	.0137	6.36	.2335	5.41	.0547
"	28.0	21.9	.0086	6.39	.1583	5.40	.0530

TABLE II.

II. Oxidation Curve, after $2\frac{1}{2}$ *hours. Nov.* 19. $T = 26.1°$; $R = 5$ *ohms. Electrodes and solution undisturbed.* $K = 30.56$; $P = .101$; $KP = 3.09$.

Cap.	dC	dR	I	ρ	$(1-e^{-KI})$	r	P
0.1	178.0	161.0	.6307	5.53	1.0000	5.37	
0.2	194.7	169.5	.3320	5.74	1.0000	5.44	
0.6	265.5	213.0	.1391	6.23	.9853	5.41	
1.0	238.3	177.7	.0696	6.70	.8808	5.44	.1067
	127.8	87.5	.0343	7.30	.6492	5.39	.0975
	54.8	34.7	.0136	7.90	.3399	5.38	.0979
3.2	109.0	67.0	.0082	8.13	.2219	5.40	

It is unnecessary to give the data for the third oxidation curve, as the changes there have become so great that the formula no longer gives any satisfactory results. While, in general, the changes are in the same direction—K having increased to about 46 and P to .21—the values obtained for r vary much more widely than the allowable amount from the constant value demanded by the formula.

Another observation, with the same solution and another pair of electrodes, is given here, for purposes of comparison.[1]

[1] See also Tables XXVII.–XXVIII. of this paper.

TABLE III.

Copper Electrodes in $CuSO_4$ (25 *G. in* 1 *L.*). *Nov.* 26. $T = 23.0°$; $R = 5.0$ *ohms*; $K = 30$; $P = .054$; $KP = 1.62$.

Cap.	dC	dR	I	ρ	$(1-e^{-KI})$	r	P
.10	187	164	.6425	5.70	1.0000	5.62	
.25	251	216	.3385	5.81	1.0000	.65	
.50	210	173	.1356	6.08	.9283	.67	
1.00	220	174	.0682	6.32	.8708	.63	.0549
3.20	370	278	.0341	6.67	.6400	.63	.0531
	156	111	.0136	7.03	.3350	.65	.0549
	95	66.5	.0082	7.14	.2178	.65	

The curve, for observed and calculated values for ρ, for a set of observations with copper in $CuSO_4$, is given on Plate III., No. 2. It will be seen that again, as in the former investigation with these materials,[1] there is good agreement between the values thus obtained. While it was evident, then, that with copper electrodes, freshly introduced into a solution of copper sulphate, results in agreement with the theory of Wiedeburg could be obtained, it was desirable, in order that extended observations might be made, that a metal be used less subject to the disturbing influence here encountered. Upon the supposition that this was due to oxidation, the next metal tried was silver, in a solution of silver nitrate.

OBSERVATIONS WITH SILVER IN SILVER NITRATE.

Into a solution of $AgNO_3$, 100 g. in 1 liter at 20°, the electrodes, silver plates, 7.9 × 12 cm., were introduced and successive observations made, as had been done with the copper. These observations extended through a period of five days; and showed a similar increase in the range of apparent resistance. The longer the plates remained in the solution, the greater this range became, as will be seen by the following table.

TABLE IV.

Silver in $AgNO_3$. *Time change in* ρ.

No. of Observation.	Interval.	Range of Apparent Resistance.
1	53 min.	1.11 to 3.40 *i. e.*, 2.29 ohms.
2	4 hours.	1.12 to 4.88 " 3.76 "
3	60 "	1.19 to 5.45 " 4.26 "
4	74 "	1.11 to 6.42 " 5.31 "

[1] Guthe, K.E., PHYS. REV., Vol. VII., p. 197.

It is to be noted that here again, as with the copper, there is no increase in the real resistance. Correcting for temperature the curves all start at the same point; while the range through which the apparent resistance changes is more than doubled. That this phenomenon is due to oxidation is impossible; for, as far as could be detected, the plates were as clean and bright at the end of the test as when placed in the solution. Further, the plates were then removed from the cell and burnished; then replaced in the cell; and in the next five days, showed only the following change.

TABLE V.

No. of Observation.	Interval.	Range of Apparent Resistance.
1	50 min.	1.27 to 9.00 *i. e.*, 7.73 ohms.
2	5 days.	1.38 to 9.48 " 8.10 "

An investigation, as to whether this change is one of the electrodes or the solution, while of great interest, would, it was felt, carry us too far from the purpose of the work in hand, especially as a difficulty, not encountered with the copper, was met with here. It consisted in the difficulty of obtaining constant readings. The deflections would slowly increase, as they were repeated, becoming constant at last for a moment, and falling then to a lower point. If now the current were reversed, the resulting reading was at first much the lowest yet obtained. After several readings had been taken, it would pass through the same changes observed before reversing. It was thus constant at three points; giving a minimum, a mean, and a maximum curve. Such a group of curves is given on Plate II., Fig. 3, Nos. VII., VIII., IX.

An explanation of the phenomena just described, in conformity to the theory of Wiedeburg, is quite possible. We need only assume that absorption of the ions by the electrodes occurs, to be in a position to understand these changes. When the first currents pass, absorption is large, and the resulting polarization is cut down. Repeated passing of the current in one direction fills the kathode, practically, and the polarization rises to the fixed value possible for the time and current employed. Meanwhile the anode is destitute of absorbed Ag ions, and hence in the best condition to absorb

them. When, on reversing, it becomes the kathode, absorption is at its maximum value, and the resulting point on the p curve has its lowest position. The process repeats itself indefinitely. In accordance with this supposition we should expect, if the supposition be correct, the best agreement with the formulæ in case of those observations taken where absorption is the least. That this is the case, reference to our data shows. I give below in Table VI. the values computed from a set of observations taken immediately upon putting the electrodes in the solution; and in Table VII. those taken from the maximum curve after the electrodes have been thirty days in the solution. Comparison will show that while the errors in r in the former reach 20 per cent., in the latter they are less than 3 per cent.

TABLE VI.

Ag in $AgNO_3$. Nov. 26. $T = 19.2°$; $R = 3.0$ *ohms. Electrodes,* 7.9×12 *cm. Solution,* 100 *G. in* 1 *L. at* 17°. $K = 79.94$; $P = .0466$; $KP = 3.72$.

Cap.	dC	dR	I	ρ	$(1 - e^{-KI})$	r	P
0.2	73	197.5	.6488	1.11	1.0000	1.038	
0.6	122	313.0	.3405	1.17	1.0000	1.033	.0431
1.0	96	208.0	.1358	1.38	1.0000	1.037	.0493
3.2	191	331.0	.06745	1.73	.9954	1.043	.0474
	124.5	162.6	.0333	2.30	.9302	1.000	
	72.5	64.0	.01306	3.40	.6479	1.089	
	52.5	40.0	.00816	3.93	.4792	1.195	

TABLE VII.

Ag in $AgNO_3$. Jan. 2. $T = 16.0°$; $R = 3.0$ *ohms. Electrodes,* 7.9×12 *cm.,* 30 *days in solution. Solution* 100 *G. in* 1 *L.* H_2O *at* 17.0°. $K = 167.4$; $P = .0796$; $KP = 13.4$.

Cap.	dC	dR	I	ρ	$(1 - e^{-KI})$	r	P
0.2	92	193.5	.6317	1.43	1	1.304	
0.4	103	200.0	.3265	1.55	1	.306	
1.0	130	205.0	.1339	1.90	1	.305	.07962
3.2	273.5	327.0	.0666	2.50	1	.304	.07961
	201.5	160.0	.0327	3.78	1	.339	.07355
	158	63.0	.0129	7.52	1	.324	.08471

While the errors in the final values are far above those of observation, they are in accord with the assumption we have made. The

observations were always begun with the large currents. If absorption occurs, with consequent depolarization, we should expect the greater effect with large currents; *i. e.*, the values of K and P computed for the lower part will be too small to satisfy the upper part of the curve. While it is possible that a different arrangement in conditions, size of electrodes, concentration of solution, etc., might have given more concordant results, the difficulties in the way of using this metal for the purpose desired seemed too great to warrant its further trial at this time. The fine agreement of the values for the large currents, however, suggests the possibility of making this combination the basis of a later investigation as to the cause of the time change which occurs upon the standing of the electrodes in solution.

Platinum Electrodes in Sulphuric Acid.

Some observations, made in the earlier investigations by Dr. Guthe, with platinized platinum electrodes, showed a sufficient agreement with the formulæ to lead to the thought that, possibly, with bright electrodes, results might be obtained in good agreement with the theory. A number of observations with such electrodes were accordingly made at this point in the work, with the hope of getting rid of the time change in the range of apparent resistance. The results conform even less than had those with the platinized electrodes, to the requirement of a constant internal resistance.

The observed values for the internal resistance show changes from 5 to 160 ohms, with current changes from .6 to .0069 of an ampère respectively, in a single set of observations. While these reduce, by computation of r, to values ranging from 1.43 to 2.02, the variations from a constant value are such as cannot be occasioned by experimental error. The same difficulty encountered with the silver was present here to a much greater degree, *i. e.*, the creeping up of the deflections.[1] Moreover, the time change in the range of apparent resistance was also present, as with copper and silver; a further indication that oxidation cannot be assigned as its cause. Table VIII. shows these changes.

This solution had been boiled to exclude air, and was covered with a layer of paraffin oil.

[1] See also Guthe, l. c.

TABLE VIII.

Bright Platinum in H_2SO_4. Time change in ρ.

Observation.	Temperature.	Interval.	Range.	Difference.
1	20.9	1 hour.	5.29–165.0	159.7
2	22.5	12 hours.	5.27–203.3	198.0
3	40.5	48 hours.	5.16–211.5	206.3

The readiness with which platinum absorbs hydrogen, and the high value found for the polarization, are possibly chargeable with the variation here found; although the conditions are much more complicated than with a metal in a solution of its own salt. It is very interesting to note that, in spite of the ill agreement in the values for the internal resistance, the mean value obtained for the polarization, 1.88 volts, is in good accord with that found by other investigators. From the numerous data at hand upon this point, only the results from a single set will be given, showing the successive values for P.

TABLE IX.

Bright Platinum in H_2SO_4. $T = 38.3°$; $R_1 = 10.0$ *ohms*; R_2, 30.0; $K = 134$; $P = 1.88$.

Cap.		dC	dR	I	ρ	$(1-e^{-KI})$	r	P
R_1	.05	71.5	162.5	.6366	4.40	1.0000	1.43	2.12
	.10	126.7	171.0	.3350	7.41	1.0000	1.88	1.97
	.20	227.0	173.0	.1695	13.10	1.0000	2.11	1.88
	.20	210.0	87.0	.0852	24.14	1.0000	2.02	1.81
R_2	.30	298.0	211.0	.0459	42.37	.9979	1.53	1.56
	.30	257.6	105.2	.0229	73.46	.9535		1.60
	.30	221.2	211.5	.0138	104.58	.8428		2.26
	.30	173.5	105.6	.0069	164.30	.6030		

ZINC IN $ZnSO_4$.

A. Unamalgamated Plates.—It was with considerable interest that this part of the investigation was approached, owing to the conflicting testimony as to the polarization of this combination. For the sake of comparison only, a series of observations was first taken with the zinc unamalgamated. The plates were of the same size as the copper ones previously employed, 10 x 13 cm.; and the solution contained 25 G. c. p. zinc sulphate in 1 L. of distilled water. An observation was attempted as soon as the cell was set

up; but the rapid time change made it impossible to complete it. To obtain an idea of the rate of this change, observations were taken

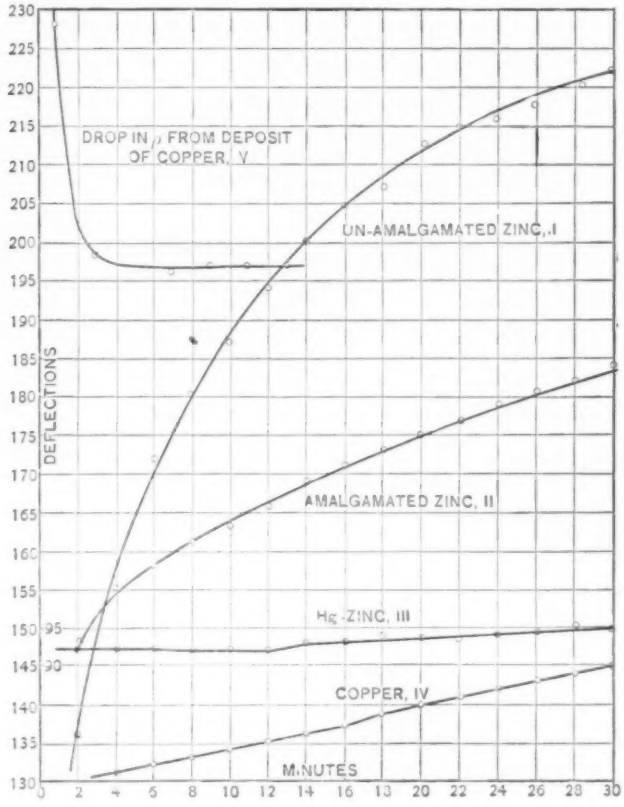


Plate I.

with large sensitiveness of the apparatus, every 20 seconds for half an hour. The results were plotted in the form of a curve, vide Plate I., No. 1.

After the cell had stood undisturbed for two hours and a half it was found possible to take observations, although repeated swings of the pendulum would cut the deflections down from 3 to 5 scale divisions. The curves for these observations, Plate II., Fig. IV., Nos. X. and XI., are very instructive. The observations began with the smallest current used—at the point where the time curve had been taken 2.5 hours before. The currents were gradually in-

creased to the largest used, and then returned to the original point. This order is indicated by the arrow heads upon the curves. These facts are evident: (*a*) the time curve shows an increase of 130 scale divisions in the first half hour, to which corresponds a change of

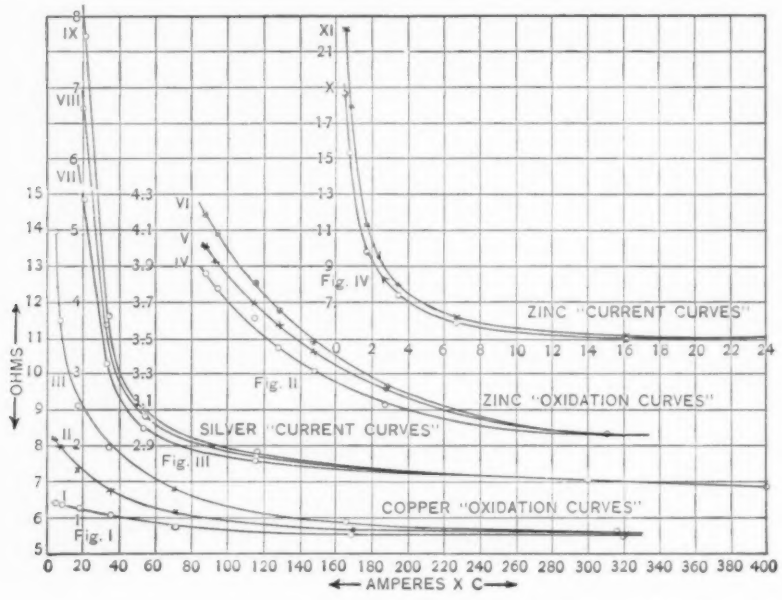


Plate II.

only 17 divisions in the next 2.5 hours; (*b*) the use of large currents cuts down the apparent resistance to a marked degree.

The behavior of these electrodes, upon further standing in the solution, is shown in the following table.

TABLE X.

Time and Current Effect on ρ. Unamalgamated Zn in $ZnSO_4$.

Hours in the Cell.	Starting Point, with Small Current.	Minimum, Largest Current.	End Point, Smallest Current.	Range.	Temp.
2.5	22.3	4.72	18.5	17.6	19.6
24	32.0	3.97	23.3	28.03	17.4
48	32.0	4.10	22.0	27.90	16.6

Consideration of the results here shown makes it clear that, whatever the cause operating to increase the apparent resistance may be,

it was in this case practically completed in the 24 hours after setting up the cell. Further, as with the platinum, silver and copper, we cannot conceive it to be an actual increase in resistance, due to an oxidation film. For here we have a cell in which the actual resistance, after 24 and 48 hours, is less than at the beginning; while the apparent resistance ρ has increased its range 60 per cent.

While it was not to be expected that a combination, so susceptible as this, would give very accurate agreement with the formulæ, yet the computation of a set of observations is not without value for comparison with those of silver and platinum. Such a completed set follows in Table XI.

TABLE XI.

Zn in $ZnSO_4$. Jan. 7. *Temp.* 19.6°. $R = 5.0$ *ohms. Unamalgamated Electrodes,* 10×13 *cm.,* $2\frac{1}{2}$ *hours in solution. Solution,* 26 *G. C. P. ZnSO, in* 1 *Liter* H_2O *at* 20.0 *degrees.* $K = 88.8$; $P = .1983$; $KP = 17.7$.

Cap.	dC	dR	I	ρ	$(1 - e^{-KI})$	r	P
0.2	295	312	.6612	4.72	1.0000	4.40	
0.2	162	160.5	.3164	5.04	1.0000	4.41	.1883
0.5	198	168	.1317	5.89	1.0000	4.39	.2083
0.9	222	151	.0657	7.41	.9971	4.40	
1.0	169	84	.0329	10.05	.9462	4.36	
1.0	103	33.6	.0132	15.33	.6896	4.81	

It will be seen that, as with the silver, the resistance r is constant until the smallest currents are reached. The same assumptions there made would suffice to explain these variations also.

B. Amalgamated plates.—It was at this point in the work that plates of varying areas were procured and observations upon them made. It was the intention to determine thus, at the same time, the conformity of the amalgamated plates to the theory, and the relation of the constants to the areas of the electrodes. The discussion of the latter question having been left for the second part of this paper, it is as well to defer to the same place the description of the preliminary work done with these plates, as it mainly was intended to bear especially upon that phase of the determination. It will be sufficient to give here the results bearing directly upon the question: Does Wiedeburg's formula satisfy the curves obtained with amalgamated zinc?

Zinc plates, especially prepared for battery use, were procured, cleaned with some care, amalgamated, and investigated as follows: First, as with the unamalgamated zinc, a time curve was taken—vide Plate I., No. II. It was found that, even with amalgamated zinc, the same time effect is active: the apparent resistance increases merely from the standing of the plates in the solution.

Successive observations were then taken, as with the copper electrodes. The resulting curves are shown in Plate II., Fig. II., Nos. IV., V., VI., where they may be compared directly with those obtained with the copper. There was a very slight increase here in the real resistance, only .15 of an ohm from the first to last observation. Part of this, if not all, is due to a fall in temperature of 0.2°. That better comparison may be possible, the curves have all been referred to the same starting point on the largest current used. The plates were only one eighth the area of those used, unamalgamated, and the solution was one containing 150 grammes in 1 liter, at 17.0°. The time consumed in taking the observations was one and a half hours. The range of increase of ρ is shown in Table XII.

TABLE XII.

Amalgamated Zinc in $ZnSO_4$. Time and Current Change in ρ.

Observation.	Interval.	Range.	Difference.	Temperature.
1	30 min.	3.86–2.97	0.89 ohms.	19.0
2	"	4.13–3.07	1.06 "	18.9
3	"	4.33–3.12	1.21 "	18.8

TABLE XIII.

Amalgamated Zinc in $ZnSO_4$. Feb. 2. $T = 19.8°$. $R = 2.0$ ohms. Zinc Plates, 1. Solution (for all observations), 150 G. in 1 L. $K = 6.0$; $P = .0166$; $KP = .0996$.

Cap.	dC	dR	I	ρ	$(1 - e^{-KI})$	r	P
0.5	281	350	.6835	1.606	.9837	1.584	
0.5	142	174	.3408	1.632	.8706	1.593	.0179
0.5	953	116	.2275	1.643	.7446	1.590	.0152
0.7	100.8	122	.1707	1.651	.6409	1.593	.0118
1.0	72	86.7	.0849	1.661	.3972	1.585	

It will be seen that, even with well amalgamated zinc, the difficulties encountered with metals formerly used, are not avoided.

While not so rapid in the first stages of the changes due to standing, the cell seems more susceptible to current effects; and gave often very indifferent curves. From the large number of observations, those given in tables XIII.–XVIII. are selected; showing to what degree the formula fits.

TABLE XIV.

Zinc Plates, 8. $K = 17.4$; $P = .1162$; $KP = 2.08$. *Jan.* 31. T, 17.0; R, 3.0 *ohms.*

Cap.	dC	dR	I	ρ	$(1 - e^{-KI})$	r	P
.2	186.5	191	.6236	2.93	1.0000	2.745	
.2	100.8	97	.3170	3.12	.9960	2.749	
.4	115.0	100	.1632	3.45	.9416	2.780	
.7	146.0	119	.1110	3.68	.8551	2.777	.1231
.9	146.0	114.8	.0833	3.82	.7652	2.749	.1159
1.0	133.5	101.4	.0662	3.95	.6840	2.749	.1096

TABLE XV.

Zinc Plates, 16. $K = 18.0$; $P = .1634$; $KP = 2.88$. *Feb.* 2. $T = 19.4$; $R = 4.0$ *ohms.*

Cap.	dC	dR	I	ρ	$(1 - e^{-KI})$	r	P
.1	105.5	129	.6317	3.721	1.0000	3.014	
.2	116.0	132	.3208	3.515	.9969	3.033	
.3	127.8	136	.2220	3.774	.9816	3.037	
.3	101.0	102	.1665	3.961	.9501	3.028	.1669
.4	112.0	108.8	.1334	4.147	.9094	3.027	.1619
.5	124.0	115.8	.1134	4.283	.8701	3.030	.1613

TABLE XVI.[1]

Amalgamated Zinc, 10 × 13 *cm., in solution* $ZnSO_4$, 25 *G. in* 1 *Liter. Jan.* 14. T, 24.0; R. = 1.0 *ohm.* $K = 9.7$; $P = .03369$; $KP = .33$.

Cap.	dC	dR	I	ρ	$(1 - e^{-KI})$	r	P
0.5	259	165	.6464	1.57	.9983	1.517	
0.5	135	83.3	.3263	1.62	.9605	1.521	.0333
1.0	114	67	.1312	1.70	.7212	1.515	.0334
3.2	185.5	105	.0643	1.77	.4708	1.520	.0343
3.2	94	52	.0318	1.81	.2703	1.521	

[1] The curve showing agreement between observed and computed values for these observations, will be found on Plate III., No. III.

TABLE XVII.

Amalgamated Zinc, 5 × 6.5 *cm. Jan.* 19. *T*, 23.0; *R*, 3.0 *ohms.* $K = 20$; $P = .052$; $KP = 1.04$.

Cap.	dC	dR	I	ρ	$(1-e^{-KI})$	r	P
0.2	104.5	202	.6594	1.55	1.0000	1.489	
0.2	56	102	.3330	1.65	.9987	1.491	.05331
0.9 }	116	191	.1386 }	1.84	.9381	1.488	.05070
1.0 }	132	214	.1397 }				
1.0	42	106	.0686	2.04	.7462	1.492	.05146
3.2	123.5	166	.0339	2.23	.4921	1.479	
3.2	52.5	65	.0134	2.42	.2356	1.484	

TABLE XVIII.

Amalgamated Zinc Plate 2.5 × 6.5 *cm. Jan.* 21. *T*, 23.0; *R*, 5.0 *ohms.* $K = 20$; $P = .0676$; $KP = 13.5$.

Cap.	dC	dR	I	ρ	$(1-e^{-KI})$	r	P
0.2	276	312	.6112	4.437	1.0000	4.311	
0.2	145	161	.3154	4.503	.9982	4.290	.0691
0.5	160	168	.1324	4.762	.9292	4.260	.0683
1.0	171	170	.0666	5.029	.7329	4.326	.0702
3.2	281	265.3	.03248	5.296	.4777	4.301	.0627
	114	104	.01273	5.481	.2249	4.288	
	72	65	.00796	5.538	.1471	4.290	

NOTE.

Franz Emil Melde.—Franz Emil Melde was born on the 11th of March, 1832, at Grossenlueder near Fulda. He was the son of the village apothecary. He attended school in his native place until twelve years of age, when he entered the Gymnasium at Fulda; from which institution he went to the University at Marburg in order to devote himself to the study of physics and mathematics. After the completion of his course, he taught for a short time at Hanau and in 1860 accepted a position as assistant in the Mathematical and Physical Institute of his alma mater under Professor Gerling.

Melde's first published work which was accepted as a thesis for the doctorate was entitled, *Ueber einige krumme Flächen, welche von Ebenen parallel einer bestimmten Ebene durchschnitten, als Durchschmittsfigur einen Kegelschnitt liefern.*

A year later followed his paper on *The Production of Standing Waves in Strings.* In 1864, Melde was appointed extraordinary professor and on the 19th of April, 1866, he became ordinary Professor of Physics and Astronomy at the University of Marburg. For nearly 35 years he was the director of the institute which he had entered as assistant. After a long illness he died on the 17th of March, 1901.

Melde devoted himself especially to acoustics to which subject he has contributed a series of important investigations. Aided by his rare skill as a musician and by his unusually accurate ear, he introduced new methods of experimentation which are of lasting value and opened out new fields for study. Among the best known of his contributions to science are his recently perfected methods for the determination of the frequency of tones of high pitch and his investigations upon the vibration of strings, plates and bells. He was the inventor likewise of many beautiful forms of apparatus for the investigation and demonstration of the phenomena of vibration the best known of which is the kaleidophon. One of his most important researches was upon the *Estimation of the Upper Limit of Audibility.* In 1883 Melde published a text-book on acoustics. In 1888 appeared his well-known monograph entitled *Chladni's Leben und Wirken.*

Melde's activity showed itself likewise in other departments of physics. His researches upon the flow of liquids and upon the formation of bubbles in cylindrical tubes are well known. Astronomy is indebted to

him for a treatise on the *Measurement of Time*, meteorology for his memoir on the *Cloudless Days observed at the Meteorological Station at Marburg during the years 1886–1894*. This station, which was established through Melde's influence in 1865 by the Hessian government, was patterned after the existing stations in Prussia.

An entire generation of physicists, chemists, medical students and pharmacists have been educated in Melde's lecture room and laboratory. As an experimenter he possessed extraordinary skill and he succeeded with the simplest means to produce from wood, glass, cork and sealing wax, apparatus with which to carry out the most precise investigations. Outwardly he was not infrequently rough and curt, but he possessed a strong sense of humor which cropped out continually in the course of his lectures.

KARL SCHAUM.

NEW BOOKS.

The Elements of Physics for use in High Schools (2d Edition). By HENRY CREW, Ph.D. The Macmillan Co., New York.

In the revised edition of Crew's Physics an already good book is distinctly improved for the high school teacher by the modification of some of its more mathematical parts.

The more important changes are as follows: All use of the method of limits and of trigonometric functions has been abandoned, English letters have been used as symbols in place of Greek, except π, and the number of problems has been increased.

We believe all of these changes are in the right direction. Symbols afford an invaluable shorthand to the student who is conversant with them, and but for the memory of Faraday one would be tempted to say that no advance beyond the most elementary stage is possible without them, but still the more directly the simple facts of physics are presented to the beginner the better. The student should have the facts so presented that he may have a clear mental picture of them unencumbered by symbols or formulas. Of course formulas have an important place and must be used, but in an elementary book they should be kept strictly subordinate.

The disposition to teach physics as though it were a branch of mathematics is illustrated in a definition found in a recent text-book of physics, where the *thermal capacity* of a body is said to be "the quotient of the heat received by the rise of temperature produced." While such a statement may express the process by which the quantity defined is calculated, it is vicious in that it fails to bring out clearly the physical concept. The student should think of thermal capacity not as a quotient, but as a certain quantity of heat.

The book under consideration is certainly entirely free from this defect. It develops the subject in a remarkably clear and exact way, the relations between phenomena being well brought out. It is a book well adapted to lay a sound foundation for more advanced study.

A. L. KIMBALL.

One Thousand Problems in Physics. By W. H. SNYDER and I. O. PALMER. Boston, Ginn & Co., 1900. Pp. 142.

This book contains over a thousand problems intended to supplement laboratory and lecture courses in preparatory and high schools. Prob-

lems of this kind are of great value provided they are of a practical character, clearly stated, and selected to illustrate physical principles rather than as examples in applied mathematics. While the greater part of these problems are of the desirable kind, the number is greater than the average pupil can use to advantage, and it is believed the book as a whole would be improved by the elimination of at least a hundred of the thousand problems.

GEO. A. HOADLEY.

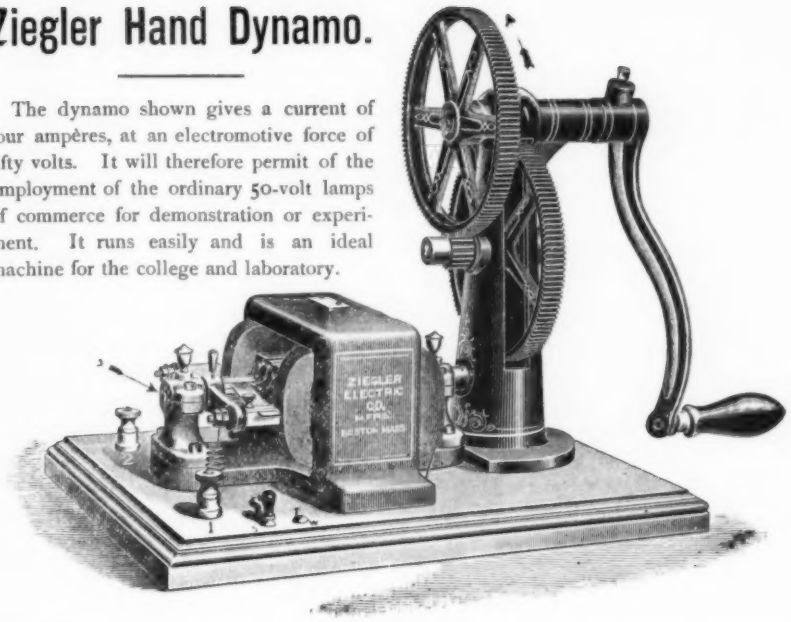
Notes and Questions for the Dynamo Laboratory. By F. C. CALDWELL and F. A. FISH. Columbus, O., Fred J. Heer, 1900. Pp. 67.

This little volume consists of a brief chapter of instructions to students in the dynamo laboratory followed by sets of questions upon nearly all the topics in direct and alternating current work usually included in the laboratory courses of our technical schools. There is likewise a set of tables of units, symbols and the physical constants of metals, a page of conventional forms to be used in the diagrams of laboratory reports and a four-place logarithm table.

While planned with special reference to the work in electrical engineering in the Ohio State University, the questions will doubtless be found useful to instructors in other institutions. E. L. N.

Ziegler Hand Dynamo.

The dynamo shown gives a current of four ampères, at an electromotive force of fifty volts. It will therefore permit of the employment of the ordinary 50-volt lamps of commerce for demonstration or experiment. It runs easily and is an ideal machine for the college and laboratory.



ZIEGLER ELECTRIC CO., 141 Franklin St., BOSTON, MASS.

Send for a copy of Physical Catalogue No. 10.

RECENT BOOKS ON MECHANICS, Etc.

The Principles of Mechanics

An Elementary Exposition of Kinematical and Dynamical Mechanics.

By FREDERICK SLATE, Prof. of Physics, University of California. Part I., pp. x + 299. **$1.90** *net.*

The needs of college students at an elementary stage are considered; but also the value of Mechanics as a system of organized thought, of distinct culture value.

A Treatise on the Theory of Screws

An exhaustive thoroughly illustrated Treatise.

By Sir ROBERT STOWELL BALL, LL.D., F.R.S., Lowndean Professor of Astronomy and Geometry in the University of Cambridge. 8vo, **$5.50** *net.*

A Manual of Elementary Science

A course of Work in Physics, Chemistry and Astronomy.

By R. A. GREGORY, F.R.A.S., Queens College, and A. T. SIMMONS, Assoc. of the Royal College of Science, London.

Practical Advice for Marine Engineers

Second edition.

By CHARLES W. ROBERTS, viii+150. Cloth, **75**c.

THE MACMILLAN COMPANY, 66 Fifth Avenue, New York.

A History of Physics

In Its Elementary Branches, including the Evolution of Physical Laboratories

By **FLORIAN CAJORI, Ph.D.**

Professor of Physics in Colorado College.

Cloth Cr. 8vo, $1.60 *net.*

This brief popular History gives in broad outline the development of the science of physics from antiquity to the present time. It contains also a more complete statement than is found elsewhere of the evolution of physical laboratories in Europe and America. The book, while of interest to the general reader, is primarily intended for students and teachers of physics. The conviction is growing that, by a judicious introduction of historical matter, a science can be made more attractive. Moreover, the general view of the development of the human intellect which the history of a science affords is in itself stimulating and liberalizing.

"Prof. Cajori has followed his 'History of Mathematics' with a 'History of Physics' that is *even more interesting and valuable.* . . . Every teacher and student of physics should read it and add it to his library. It shows careful study, enthusiasm and a comprehensive grasp of the subject."—*Journal of Education.*

BY THE SAME AUTHOR

A History of Mathematics

Cloth 8vo, $3.50 *net.*

"What we have a right to expect in such a handbook is an agreeable narrative of the most material events in the history of mathematics, and this Professor Cajori incontestably supplies. The book was much wanted."—*The Nation.*

"A scholarship both wide and deep is manifest in this *History of Mathematics* which the author has infused with his own ardor in this department of science."

—*Journal of Education.*

A History of Elementary Mathematics

Cloth 12mo, $1.50 *net.*

"A most instructive, and at the same time a very readable piece of work, full of curious facts."—*The Bookman.*

"By no means an abridged edition of *The History of Mathematics.* It is an entirely new book, giving a somewhat detailed account of the rise and progress of Arithmetic, Algebra and Geometry. The book should be read by all teachers of these subjects, and by mathematical students generally."

—*American Mathematical Monthly.*

Chemical Lecture Experiments

By **Francis Gayno Benedict,** Instructor in Chemistry in Wesleyan University.
12mo, cloth, $2.00 *net.*

The material here presented has been in a measure prepared with reference to its use by students desiring collateral reading in connection with experimental lectures. An elaboration of the Laboratory Manual, the book may also be used by students for the preparation of many compounds not considered in elementary text-books.

THE MACMILLAN COMPANY, Publishers, New York

New Books on Astronomy, etc.

Among THE MACMILLAN COMPANY'S Publications

By Sir ROBERT BALL, LL.D.

The Elements of Astronomy

By the author of "Starland," "Atlas of Astronomy," "The Story of the Sun," "The Theory of Screws," etc., etc.

By Sir ROBERT BALL, LL.D., Lowndean Professor of Astronomy and Geometry in the University of Cambridge, formerly Royal Astronomer of Ireland. Cloth, illustrated, **80 cents** *net.*

By JOHN COUCH ADAMS

Lectures on the Lunar Theory

The Lectures of Prof. Ball's predecessor, edited by R. A. SAMPSON, University of Durham.

By JOHN COUCH ADAMS, M.A., F.R.S., late Lowndean Professor of Astronomy and Geometry in the University of Cambridge. Cloth, 8vo, **$1.25** *net.*

By W. HASTIE, D.D.

Kant's Cosmogony

Kant's Essay on the Retardation of the Rotation of the Earth and his Natural History and Theory of the Heavens.

Edited and Translated by W. HASTIE, D.D., Professor of Divinity, University of Glasgow. With an Introduction and Appendices by and a portrait of THOMAS WRIGHT, University of Durham. Cloth, cr. 8vo, **$1.90** *net.*

By A. W. BICKERTON

The Romance of the Heavens

By A. W. BICKERTON, Professor of Chemistry, Canterbury College, Christchurch, New Zealand University, Author of "The Romance of the Earth." Cloth, 12mo, **$1.25.**

By Sir NORMAN LOCKYER, K.C.B.

Recent and Coming Eclipses

Accounts of Observations in India, 1898, with Conditions of Eclipses of 1900, 1901 and 1905.

By Sir NORMAN LOCKYER, K.C.B., F.R.S., author of "The Sun's Place in Nature," etc. *Second Edition.* Illustrated. Cloth, 8vo, **$2.00** *net.*

Send for our latest classified catalogue. Address,

THE MACMILLAN COMPANY, 66 Fifth Ave., New York

Standard Text-Books on General Physics

The Elements of Physics

FOR USE IN HIGH SCHOOLS.

By HENRY CREW, Ph.D., Northwestern University.

Second Edition, Revised, **Cloth. $1.10,** *net.*

Elements of Theoretical Physics

By DR. C. CHRISTIANSEN

Professor of Physics, University of Copenhagen

TRANSLATED INTO ENGLISH BY

W.F. MAGIE, Ph.D., Professor of Physics, Princeton University **Cloth. 8vo. $3.25, net**

Problems and Questions in Physics

CHARLES P. MATTHEWS, M.E., AND JOHN SHEARER, B.S.

Purdue University *Cornell University*

8vo. Cloth. pp. 247 + 4. Price $1.60, net

An Intermediate Course of Practical Physics

By A. SCHUSTER, Ph.D., F.R.S., AND C. H. LEES, D.Sc.

Owens College, Manchester *Owens College, Manchester*

12mo. Cloth. pp. xv + 248. Price $1.10 net.

By the same authors

Advanced Exercises in Practical Physics

Cambridge University Press Series. Cloth. pp. x + 368, 8vo, $2.00, *net.*

Lessons on Elementary Practical Physics

By BALFOUR STEWART, A.M., LL.D., F.R.S., AND W. W. HALDANE GEE

Vol. I. **General Physical Processes.** 12mo. $1.50, *net*

Vol. II. **Electricity and Magnetism.** $2.25, *net*

Vol. III. Part I. **Practical Acoustics.** $1.10, *net*

Part II. **Heat and Light.** *In Press*

Laboratory Manual of Physics and Applied Electricity

Arranged and Edited by EDWARD L. NICHOLS

Professor of Physics in Cornell University

IN TWO VOLUMES **Vol. I. Cloth. Price $3.00, net**

JUNIOR COURSE IN GENERAL PHYSICS. By ERNEST MERRITT and FREDERICK J. ROGERS. **Vol. II. Cloth. pp. 444. Price $3.25, net**

SENIOR COURSES AND OUTLINES OF ADVANCED WORK By GEORGE S. MOLER, FREDERICK BEDELL, HOMER S. HOTCHKISS, CHAS. P. MATTHEWS, and THE EDITOR.

A large proportion of the students for whom primarily this Manual is intended are preparing to become engineers, and special attention has been devoted to the needs of that class of readers.

THE MACMILLAN COMPANY New York: 66 Fifth Avenue

BOSTON CHICAGO SAN FRANCISCO

THE CHEAPEST BOOKS IN

Science, Philosophy and Psychology

Now Publishing in America.

High Grade Paper. Large Print. Sewed Bindings. These books are reprints of standard scientific works, philosophical classics, etc.

A BOON TO STUDENTS.

Note the following contents and the reasonable prices of

THE RELIGION OF SCIENCE LIBRARY

No. 1. **The Religion of Science.** By PAUL CARUS. 25 cents (1s. 6d.).
2. **Three Introductory Lectures on the Science of Thought.** By F. M x MÜLLER. 25 cents (1s. 6d.).
3. **Three Lectures on the Science of Language.** By F. M x MÜLLER. 25 cents (1s. 6d.).
4. **The Diseases of Personality.** By TH. RIBOT. 25 cents (1s. 6d.).
5. **The Psychology of Attention.** By TH. RIBOT. 25 cents (1s. 6d.).
6. **The Psychic Life of Micro-Organisms.** By ALFRED BIET. 25 cents (1s. 6d.).
7. **The Nature of the State.** By PAUL CARUS. 15 cents (9d.).
8. **On Double Consciousness.** By ALFRED BIET. 15 cents (9d.).
9. **Fundamental Problems.** By PAUL CARUS. Pages 373. 50 cents (2s. 6d.).
10. **The Diseases of the Will.** By TH. RIBOT. 25 cents (1s. 6d.).
11. **The Origin of Language,** and **The Logos Theory.** By LUDWIG NOIRÉ. 15c. (9d.).
12. **The Free Trade Struggle in England.** By GEN M. M. TRUMBULL. 25 cents (1s. 6d.).
13. **Wheelbarrow on the Labor Question.** 35 cents (2s.).
14. **The Gospel of Buddha.** By PAUL CRUS. 35 cents (2s.).
15. **Primer of Philosophy.** By PAUL CARUS. 25 cents (1s. 6d.).
16. **On Memory,** and **The Specific Energies of the Nervous System.** By PROF. EWALD HERING. 15 cents (9d.).
17. **The Redemption of the Brahman.** A Novel. By R. GARBE. 25 cents (1s. 6d.).
18. **An Examination of Weismannism.** By J. G. ROMANES. 35 cents.
19. **On Germinal Selection.** By AUGUST WEISMANN. 25 cents (1s. 6d.).
20. **Lovers Three Thousand Years Ago.** By T. A. GOODWIN. (Out of Print.)
21. **Popular Scientific Lectures.** By ERNST MACH. 50 cents (2s. 6d).
22. **Ancient India: Its Language and Religions.** By H. OLDENBERG. 25 cents (1s. 6d.).
23. **The Prophets of Israel.** By C. H. CORNILL. 25 cents (1s. 6d.).
24. **Homilies of Science.** By PAUL CARUS. 35 cents (2s.).
25. **Thoughts on Religion.** By G. J. ROMANES. 50 cents (2s. 6d.).
26. **Philosophy of Ancient India.** By RICHARD GARBE. 25 cents (1s. 6d.).
27. **Martin Luther.** By GUSTAV FREYTAG. 25 cents (1s. 6d.).
28. **English Secularism.** By GEORGE JACOB HOLYOAKE. 25 cents (1s. 6d.).
29. **On Orthogenesis** By TH. EIMER. 25 cents (1s. 6d.).
30. **Chinese Philosophy.** By PAUL CARUS. 25 cents (1s. 6d.).
31. **The Lost Manuscript.** By GUSTAV FREYTAG. 60 cents (3s.).
32. **A Mechanico-Physiological Theory of Organic Evolution.** By CARL VON NÄGELI. 15 cents (9d.).
33. **Chinese Fiction.** By the REV. GEORGE T. CANDLIN. 15 cents (9d.).
34. **Mathematical Essays and Recreations.** By H. SCHUBERT. 25 cents (1s. 6d.).
35. **The Ethical Problem.** By PAUL CARUS. 50 cents (2s. 6d.).
36. **Buddhism and Its Christian Critics.** By PAUL CARUS. 50 cents (2s. 6d.).
37. **Psychology for Beginners.** H. M. STANLEY. 20 cents (1s.).
38. **Discourse on Method.** By RENÉ DESCARTES. 25 cents (1s. 6d.).
39. **The Dawn of a New Era.** By PAUL CARUS. 15 cents (9d.).
40. **Kant and Spencer.** By PAUL CARUS. 20 cents (1s.).
41. **The Soul of Man.** By PAUL CARUS. 75 cents (3s. 6d.).
42. **World's Congress Addresses.** By C. C. BONNEY. 15 cents (9d.).
43. **The Gospel According to Darwin.** By WOODS HUTCHINSON. 50 cents (2s. 9d.).
44. **Whence and Whither.** By PAUL CARUS. 25 cents (1s. 6d.).
45. **Enquiry Concerning the Human Understanding.** By DAVID HUME. 25c. (1s. 6d.).
46. **Enquiry Concerning the Principles of Morals.** By DVID HUME. 25c. (1s. 6d.)
47. **The Psychology of Reasoning.** By ALFRED BINET. 25 cents (1s. 6d.).
48. **Berkeley's Principles of Human Knowledge.** 25 cents (1s. 6d.).
49. **Berkeley's Three Dialogues between Hylas and Philonous.** 25 cents (1s. 6d.).

THE OPEN COURT PUBLISHING COMPANY,

324 DEARBORN ST., CHICAGO, ILL.

LONDON: KEGAN PAUL, TRENCH, TRÜBNER & CO.

The Astrophysical Journal

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

EDITED BY

GEORGE E. HALE

Director of the Yerkes Observatory

WITH THE COÖPERATION OF

THE LEADING ASTROPHYSICISTS OF THE UNITED STATES AND EUROPE

Contents of Recent Numbers

JULY 1900.

On the Spectrum of Radium . . C. RUNGE

The Velocity of Meteors as Deduced from Photographs at the Yale Observatory W. L. ELKIN

Some New Fluorescence and Afterglow Phenomena in Vacuum Tubes Containing Nitrogen . . . . . PERCIVAL LEWIS

The Effect of Some Impurities on the Spectra of Some Gases. II. PERCIVAL LEWIS

Prominences Observed at Kalocsa on May 28, 1900 . . . . . J. FÉNYI

A Suggested Explanation of the Solar Corona . . . . . J. SCHEINER

Remarks on the Construction and Adjustment of Spectrographs. II. J. HARTMANN

Note on the Spectrum of Silicon FRANZ EXNER and EDUARD HASCHEK

Pressure in the Spark EDUARD HASCHEK and HEINRICH MACHE

James Edward Keeler . . GEORGE E. HALE

Minor Contributions and Notes: A New Star in *Aquila*, E. C. PICKERING; The Yerkes Observatory of the University of Chicago, *Bulletin* No 13, GEORGE E HALE; Positions of *Eros* (433) in 1893, 1894, and 1896 EDWARD C. PICKERING

Eclipse Reports: Preliminary Results of the United States Naval Observatory Eclipse Expeditions, S. J. BROWN; A Preliminary Statement of the Results of the Smithsonian Observatory Eclipse Expedition, C. G. ABBOT; Eclipse Observations by the Princeton Party at Wadesboro, N. C., May 28, 1900, C. A. YOUNG; The Yerkes Observatory of the University of Chicago, *Bulletin* No. 14, Observations of the Total Solar Eclipse of May 28, 1900, at Wadesboro, N. C., GEORGE E. HALE; Observations of the Total Eclipse at Centerville, Norfolk County, Va., WINSLOW UPTON; Observations at Juliette, Ga., C. W. CROCKETT; Observations of the Total Solar Eclipse of May 28, 1900, by the Harvard Observatory Expedition, WILLIAM H. PICKERING; Observations of the Total Eclipse by the Vassar College Party, MARY W. WHITNEY; Observations by the Massachusetts Institute of Technology Party, ALFRED E. BURTON; Observations at Wadesboro, N. C., J. B. COIT; Observations at Southern Pines, N. C., F. E. SEAGRAVE; The Weather Bureau Observations of the Total Eclipse of May 28, 1900; Observations at Norfolk, Va., FRANK W. VERY; Observation by the Georgetown College Party, J. G. HAGEN; Persistence of the Corona After Totality, JOHN FRED MOHLER.

SEPTEMBER 1900.

The Spectra of Mercury WILLIAM B. HUFF

An Investigation on the Zeeman Effect HERBERT M. REESE

A New Theory of the *Milky Way* C. EASTON

Minor Contributions and Notes: Variable Stars in Clusters. Rate of Increase of Light, EDWARD C. PICKERING; The Yerkes Observatory of the University of Chicago, *Bulletin* No. 15, GEORGE E. HALE; Comparison of a Prism and a Grating Spectroscope, N. ERNEST DORSEY.

OCTOBER 1900.

On the Arc-Spectra of Some Metals as Influenced by an Atmosphere of Hydrogen HENRY CREW

Some Abnormal Stars in the Cluster *M 13 Herculis* . . . . E. E. BARNARD

Discovery and Period of a Small Variable Star in the Cluster *M 13 Herculis* E. E. BARNARD

Solar Phenomena, Considered in Connection with Anomalous Dispersion of Light W. H. JULIUS

Note on Inquiries as to the Escape of Gases from Atmospheres G. JOHNSTONE STONEY

The Complete Emission Function P. G. NUTTING

Rise of a Large Prominence on June 1, 1900 J. FÉNYI

Field of the Reflecting Telescope S. C. REESE

Reviews: A general catalogue of 1290 double stars discovered from 1871 to 1899 by S. W. Burnham, S. W. BURNHAM (E. E. Barnard); Photometric Revision of the Harvard Photometry during the years 1891–1894, EDWARD C. PICKERING (J. A. P.)

JANUARY 1901.

On the Period of the Solar Spots SIMON NEWCOMB

On an Apparatus for the Laboratory Demonstration of the Doppler-Fizeau Principle . . . . . A. BÉLOPOLSKY

The Radiation of a Black Body C. E. MENDENHALL and F. A. SAUNDERS

Examination of *Pleiades* and *Eros* Plates Taken with the Crossley Reflector of the Lick Observatory

On the Production of a Line Spectrum by Anomalous Dispersion, and its Application to the "Flash Spectrum" R. W. WOOD

The Nature of the Solar Corona R. W. WOOD

A Preliminary Determination of the Motion of the Solar System W. W. CAMPBELL

The Motion of ζ *Geminorum* in the Line of Sight . . . . W. W. CAMPBELL

Some Stars with Large Radial Velocities W. W. CAMPBELL

CHICAGO

The University of Chicago Press

LONDON: WM WESLEY & SON

Published every month except August and February

Subscription Price Domestic, $4.00; Foreign, $4.50

PORTRAITS

To satisfy a demand which has arisen, the publishers have arranged to issue a limited number of copies of the portraits of scientific men, that have appeared from time to time as frontispieces in the PHYSICAL REVIEW.

The portraits are printed in photogravure, on plate paper, suitable for framing, and are for sale at the very low price of 25 cents each.

NOW READY.

JOHN TYNDALL
HEINRICH HERTZ
HERMAN VON HELMHOLTZ (1876)
AUGUST KUNDT
ALFRED M. MAYER
WILLIAM A. ROGERS
GUSTAV WIEDEMANN
ROBERT BUNSEN
THOMAS PRESTON

THE PHYSICAL REVIEW

A Journal of Experimental and Theoretical Physics

CONDUCTED BY

EDWARD L. NICHOLS, ERNEST MERRITT and FREDERICK BEDELL.

LXIV. June, 1901

TABLE OF CONTENTS

The Influence of Temperature upon the Photo-electric Effect. JOHN ZELENY.

Currents and Potential on Submarine Cables produced by Sine-wave Electromotive Forces. A. C. CREHORE.

The Two Specific Heats of Gases. W. P. BOYNTON.

On a Form of Artificial Submarine Cable. AUGUSTUS TROWBRIDGE.

Force Due to "Continuous Impact." FREDERICK SLATE.

The Wilder Physical Laboratory of Dartmouth College. E. F. NICHOLS.

On a Method for the Determination of the Critical Velocity of Fluids. H. T. BARNES and E. G. COKER.

Note on Some Modifications of Electric Discharges caused by Dielectrics. K. VON WESENDONK.

A Simple Apparatus for Illustrating Forced Vibrations. JOHN R. BENTON.

New Books: *Adams:* Lectures on the Lunar Theory; *Very:* Atmospheric Radiation.

Index

LXV. July, 1901

TABLE OF CONTENTS

Frontispiece

The Effect of Gravity and Pressure on Electrolytic Action. ROLLA R. RAMSEY.

On a Newly Discovered Phenomenon Produced by Stationary Sound-Waves. BERGEN DAVIS.

On the Heat Evolved when Liquids are Brought in Contact with Powders. C. E. LINEBARGER.

On the Density of Ice. H. T. BARNES.

Note: Henry Augustus Rowland

PUBLISHED FOR CORNELL UNIVERSITY

THE MACMILLAN COMPANY